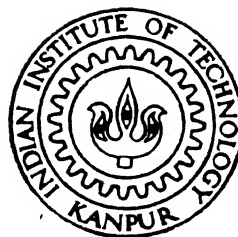


PRELIMINARY INVESTIGATIONS INTO ELECTROCHEMICAL DISCHARGE MICROWELDING OF THIN PLATES

by

V. SRIRAM

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DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

APRIL, 1997

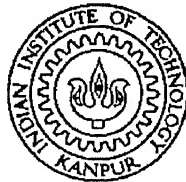
PRELIMINARY INVESTIGATIONS INTO ELECTROCHEMICAL DISCHARGE MICROWELDING OF THIN PLATES

A thesis submitted
in partial fulfillment of the requirements
for the degree of

MASTER OF TECHNOLOGY

by

V.SRIRAM



to the

**DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR**

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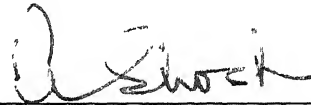
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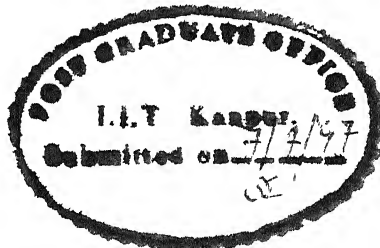
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It is certified that the work contained in this thesis entitled "*PRELIMINARY INVESTIGATIONS INTO ELECTROCHEMICAL DISCHARGE MICROWELDING OF THIN PLATES*" by *V. SRIRAM* has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

 7.4.97

Professor AMITABHA GHOSH
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Kanpur

April, 1997



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THE AUTHOR

Abstract

This thesis investigates the feasibility of using Electrochemical Discharge phenomenon for microwelding of thin plates. Only two researchers [1],[6] have explored the possibility of using this process for microwelding while many others have concentrated on ECD machining.

The objectives of this thesis are

- To investigate the feasibility of Electrochemical Discharge microwelding.
- To develop a setup to produce V-welds in thin plates.
- To establish a range of parameters in which satisfactory welding occurs.
- To arrive at an optimum range of variables depending on the strengths of the welds.

An experimental study was conducted to achieve the above objectives. A scheme in which the wire was fed between a sparking electrode and a brass plate to achieve welds was found out. This was found to produce satisfactory V-welds in thin plates. Inductance was found to be a major parameter affecting the process. It was found that no welding occurs without inductance and that an inductance of 30mH was found to be the optimum.

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Chapter 1

INTRODUCTION

1.1 Welding

Welding is defined as the process of joining two metallic components by a suitable process. This can be accomplished with the application of heat (melting and fusion) or without the application of heat (cold welding) or by applying large pressure. Welding processes can be broadly classified as follows:

- Gas welding
- Electric arc welding
- Electric resistance welding
- Special methods
- Unconventional methods

The four methods in the first four groups are widely used and well understood but those belonging to the last group are relatively new. Although unconventional methods are quite prevalent in machining, a method based on

Electrochemical Discharge has been successfully used in the welding of thin wires (like thermocouple wires).

1.2 Microwelding

This process refers to the practice of joining very thin sheets of metals or wires. They are widely used in the electronics industry. Among conventional methods laser welding has found acceptance in industry as a means of producing accurate welds at a high speed. But most conventional methods fail here because it is very difficult to produce a controlled heat source that can be concentrated at a particular place. Although lasers can be used for this purpose the costs involved are very high and are justified only when the throughput is very high.

1.3 ECD Microwelding

Electro Chemical Discharge welding comes under the list of applications of the ECD process. The main advantage of this method over conventional methods is that the discharge of energy can be accurately controlled and can be directed at a particular place without any difficulty. This makes it a suitable process for microwelding of thin plates and wires.

1.4 Electro Chemical Discharge phenomenon

Let us consider an electrolytic cell with an electrolyte and two electrodes, a cathode and an anode as shown in Fig 1.1. If an electric potential is applied between these two electrodes three types

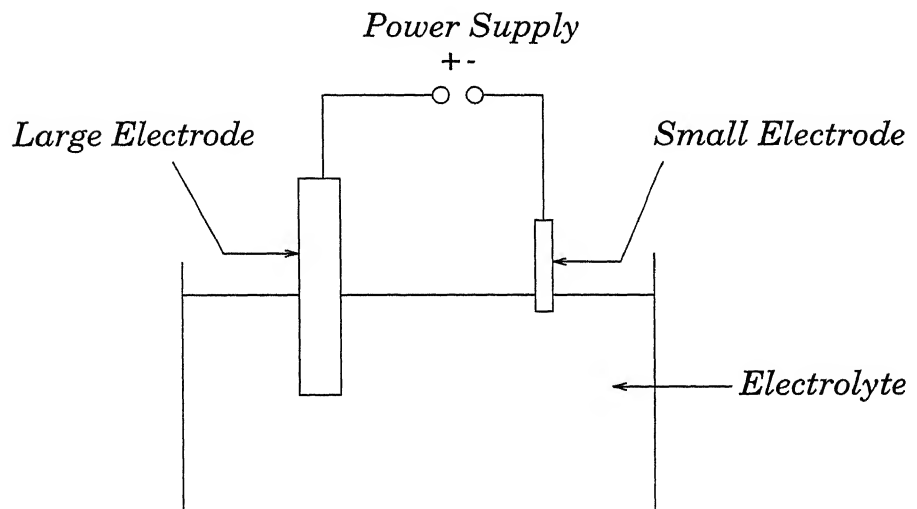
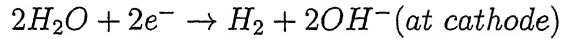
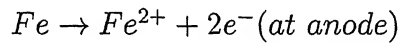


Figure 1.1: An Electrochemical Discharge cell

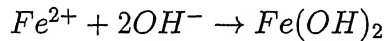
of action takes place, electrochemical action without electric discharge, electrochemical action with discharge between electrode and electrolyte and discharge between two electrodes. These are explained below.

(a) Electro Chemical action without electric discharge

This is similar to normal ECM process. For a sodium chloride electrolyte, with iron as work material, the normal reactions at the cathode and anode are as follows



The anode metal dissolves, leaving two electrons. Water receives two electrons from the cathode and as a result hydrogen gas is evolved and hydroxyl ions are produced. The positive metal ions drift towards the cathode and the negative hydroxyl ions are attracted towards the anode. The metal ions then combine with the hydroxyl ions to precipitate out as iron hydroxide as follows



Ferrous hydroxide forms an insoluble precipitate. So finally there is dissolution of the anode and generation of hydrogen gas at the cathode while the cathode shape remains intact.

(b) Electro Chemical action with electrical discharge between an electrode and electrolyte

This type of phenomenon occurs when a high electric field is developed, like across a gas bubble or across any non conducting layer. We saw previously that hydrogen gas is liberated at the cathode. The bubbles gradually grow in size and after reaching a critical size, detach themselves from the elec-

trode surface. The nucleation site density of hydrogen bubbles increases with applied voltage. When the nucleation site density becomes sufficiently high, constriction of current path takes place at the interface. This causes an increased resistance at the electrode-electrolyte interface and the ohmic heating of the electrolyte becomes significant. This heating of the electrolyte results in vapour bubble nucleation in addition hydrogen bubbles. It was noticed by Basak [1] that at the critical value of the nucleation site density, maximum possible coverage of the electrode surface occurs with full grown hemispherical bubbles. At this stage the bubble bursts instantly due to intense heating. The current through the circuit drops to zero instantly, resulting in a discharge between the electrode and the electrolyte, as contact between the electrode and the electrolyte is re-established. This process is repeated many times and the resulting spark appears in the form of a flame. It is this phenomenon which is used for microwelding.

(c) Discharge between the two electrodes

This phenomenon occurs when the two electrodes are very close together. This is not of much significance and is included here only for the sake of completeness. Therefore ECD phenomenon is mainly due to the layer of steam and hydrogen bubbles formed at the cathode. Fig 1.2 illustrates the relationship between current and voltage as this phenomenon occurs. It also illustrates the covering of the cathode by the bubbles. It can be seen that after a critical voltage the current suddenly drops to a low value with the voltage remaining almost constant. This is due to the formation of the vapour film which acts as an insulator and prevents current flow.

The phenomenon of ECD was first reported by Taylor during electrolysis of molten NaCl. Basak[1] used the circuit shown in Fig 1.3 to describe the various resistances that come into effect during ECD phenomenon. Bubble formation at the electrode surfaces results in resistances R_1 and R_2 . Due to

electrostatic force, the electrodes attract oppositely charged ions. At any point of time some of these ions are accumulated at the electrodes. This situation is analogous to a charged capacitor. Hence C_1 and C_2 are taken as capacitances at the electrode-electrolyte interface. R_e is the natural resistance of the electrolyte and C and L are inherent capacitance and inductance of the circuit. Basak[1] was the first to point out that switching action and not breakdown of the electrolyte medium is responsible for the discharge phenomenon. This led to the inductance of the circuit being identified as a major parameter in ECD processes. This result is even more significant because an external inductance can be introduced into the circuit which can be easily varied. He found out the variation of material removal rate with inductance, which is shown in Fig 1.4. He also established the variation of temperature with applied voltage which is shown in Fig 1.5.

Another important aspect of ECD is that at sufficiently high voltage the sparking is found to occur at the bottom surface and around the circumference of the electrode only. This is due to the fact that the buoyant force of the electrolyte carries away all the bubbles formed at the sides, while the bubble formed at the bottom are trapped by the electrode itself. So the bottom surface becomes fully covered by the vapour film which in turn paves the way for discharge to occur at that point.

Allesu[2] conducted detailed investigation of ECD for various manufacturing processes. One of the main findings of Allesu is that the discharge voltage increases with electrolyte flow velocity as is shown in the Fig 1.6. Allesu[2] also found that, while machining a negative tool gives a good finish while a positive tool consumes itself. This discovery is significant since in the welding technique carried out here, the tool is made the cathode. This is because the electrode should not deform during the welding process. He also found that if a positive tool is used there is higher material removal rate, since it can be operated at a higher voltage. He also conducted experiments

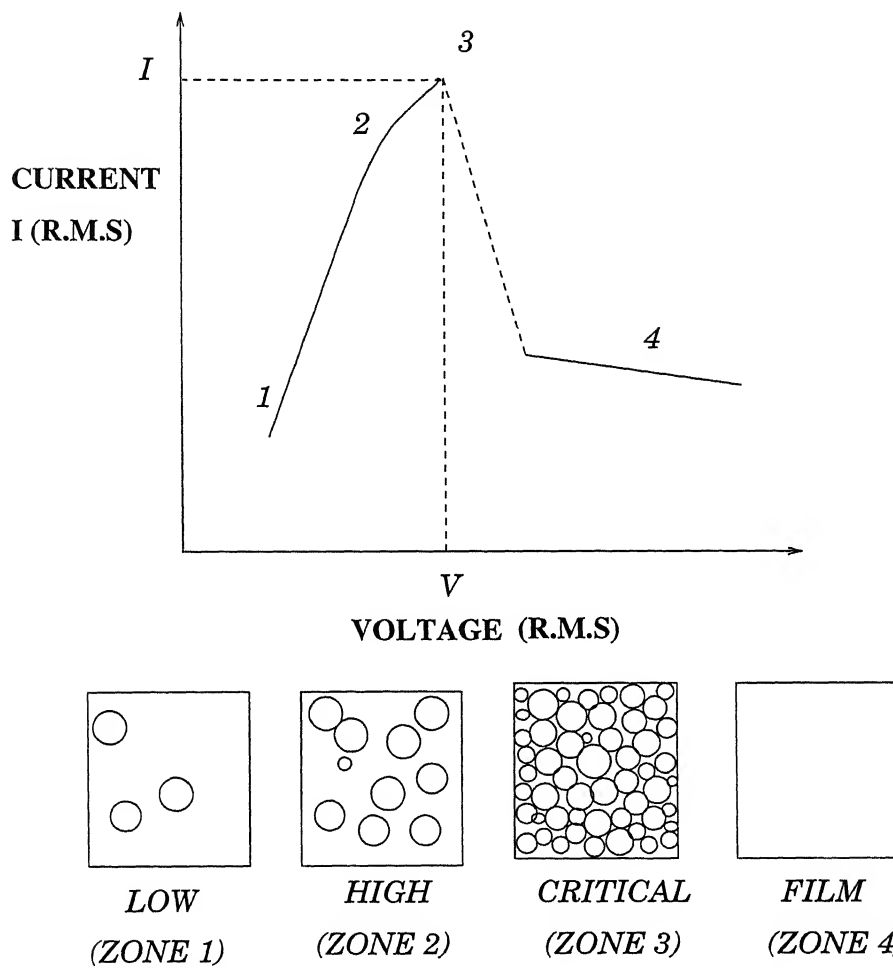


Figure 1.2: Relationship between voltage, current and bubble density

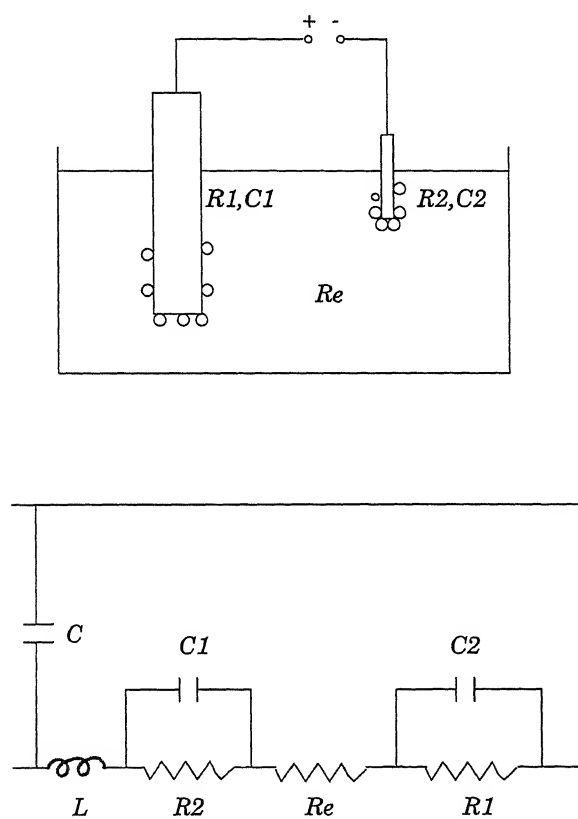


Figure 1.3: Equivalent electric circuit of ECD setup

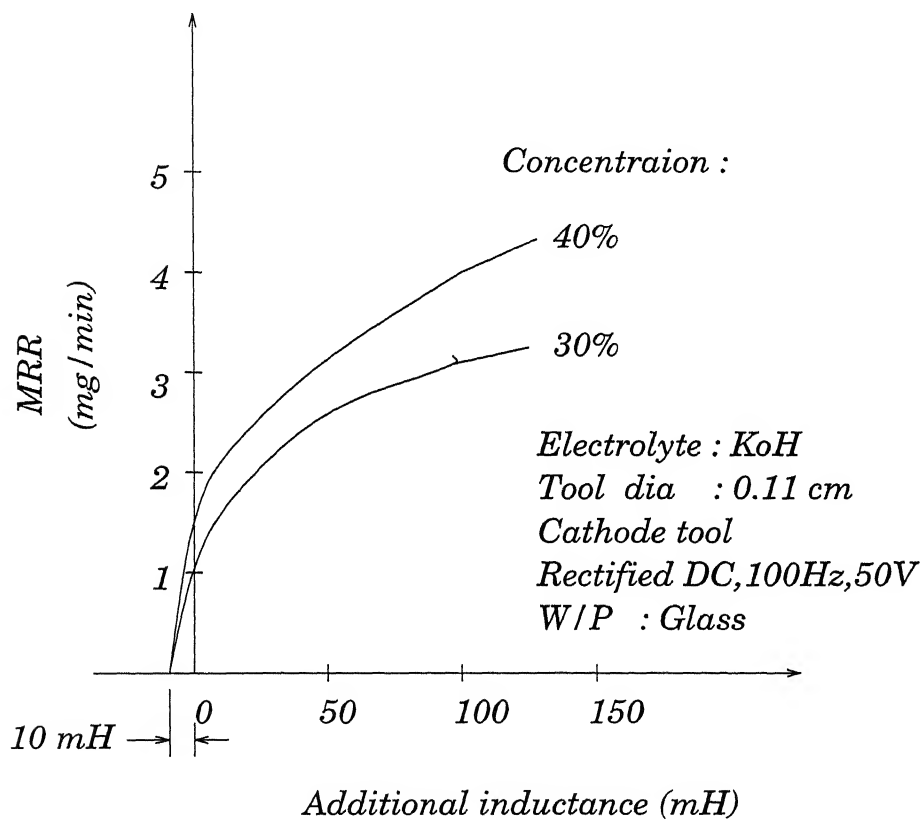


Figure 1.4: Determination of circuit inductance

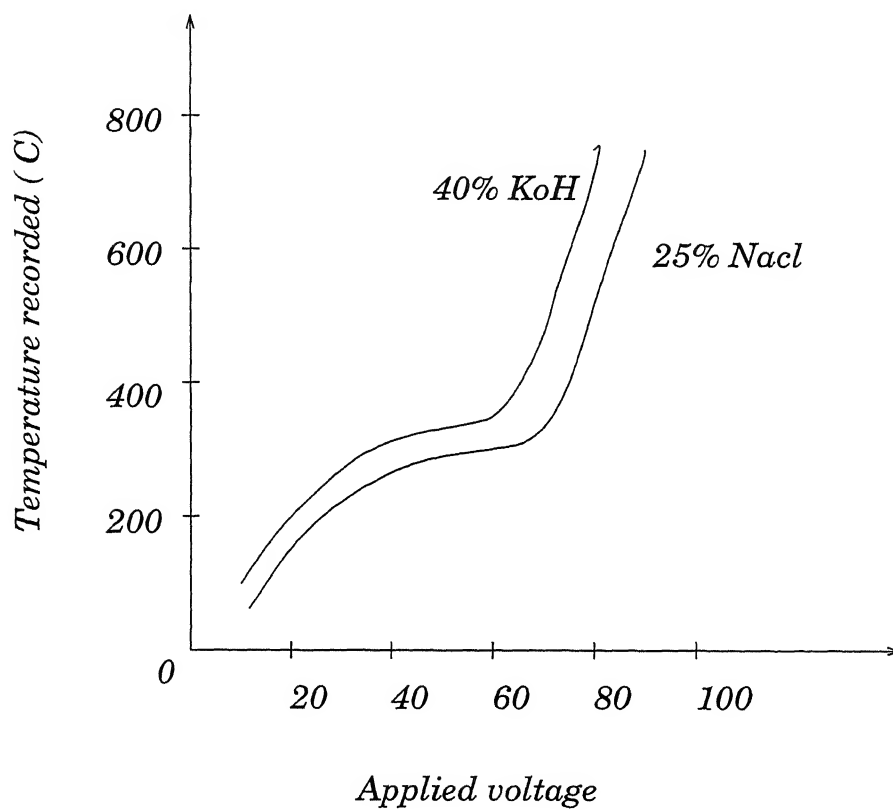


Figure 1.5: Variation of temperature with applied voltage

on other applications like engravings on glass and microwelding of thin wires and obtained positive results. Cook[3] conducted many experimental studies on ECD phenomenon. He also conducted experiments on ECD machining of nonconducting materials. He found out that the bubbles produced are strongly charged and can be made to diffuse away from the cathode, or disperse by superposing an AC voltage on the electrolysis DC voltage. He conducted tests with 35% NaOH and found that the rate of machining decreases with time as shown in the Fig 1.7. This is the characteristic of the specific tool geometry-electrolyte system. He obtained a machining rate of 0.1 in/min. The rate of machining increases with both concentration and temperature of electrolyte. This is because of the increase in the conductivity with increase in both the values. The surface produced by the pulsed power supply is much smoother than that from a DC supply. Good material removal rates were obtained with fused salts, a eutectic of NaOH and KOH. He also found that the process is capable of producing small holes at a feed rate of 0.1 in/min. V.Raghuram[7] analysed the effect of various circuit parameters on the electrolytes in ECD phenomenon. He examined the influence of various types of power supply (Rectified DC, smooth DC, rectified DC with series inductor, and smooth DC with series inductor). Basak found that the sudden drop in current, as the discharge starts, can be arrested by the introduction of series inductance. They concluded that the presence of an external inductance in the circuit had the advantage of supplying a constant power input to the cell.

ECD machining was widely investigated by many researchers. Electrochemical arc wire machining was examined by McGeough and Hofy[4]. They found that at the lowest feed, rate material removal was caused entirely by electrochemical dissolution. Under the former condition the voltage waveform was distorted, and there was no evidence of discharge action from the machining cell, usually marked by bright luminosity. At the lowest voltage used

some electrochemical discharge erosion arose, in addition to ECD, due to the smallness of the gap under these conditions. At the highest voltage, a greater amount of electrochemical discharge erosion occurred, due to the increased input energy to the zone. The feed rate had some influence on the process and acceptable machining accuracy can be obtained by using low machining voltages. At the highest feed rate, welding or short circuiting between wire and specimen occurred. He also observed that there is a decrease in specific material removal rate with an increase in the feed rate. This is because the increased feed rate results in increased sparking and this affects the cathode tool. He also found out that material removal rate increases with increase in applied voltage (due to increase in electrochemical discharge phenomenon). Jain[5] conducted many experiments on machining of composites (Glass-epoxy and Kevlar-epoxy composites). He found that the flowing electrolyte carries away the bubbles and hence is not suitable for machining and that high machining accuracy is obtained at lower value of voltage and concentration. He concluded that thermomechanical phenomenon is responsible for machining.

Limited literature is available in the field of ECD welding. Only Allesu and Parija have conducted research in this field. Allesu made preliminary investigation of ECD welding of thermocouples. This work was later followed up by Parija[6] who developed a thermal model in addition to establishing the voltage range in which proper welding occurs. This range is shown in the Fig 1.8. She also found that the intensity of discharge is very high when the power supply is smooth DC, with both inductance and capacitance present in the circuit. The capacitor increases the energy release per spark. She obtained an exponential curve for the plot between the depth of immersion and wire diameter for different materials. This is due to the increase in cross sectional area with increase in wire diameter. She also observed that for a particular wire diameter the optimal depth of immersion varies for different wire materials. This is due to the effect of the buoyant force of the electrolyte.

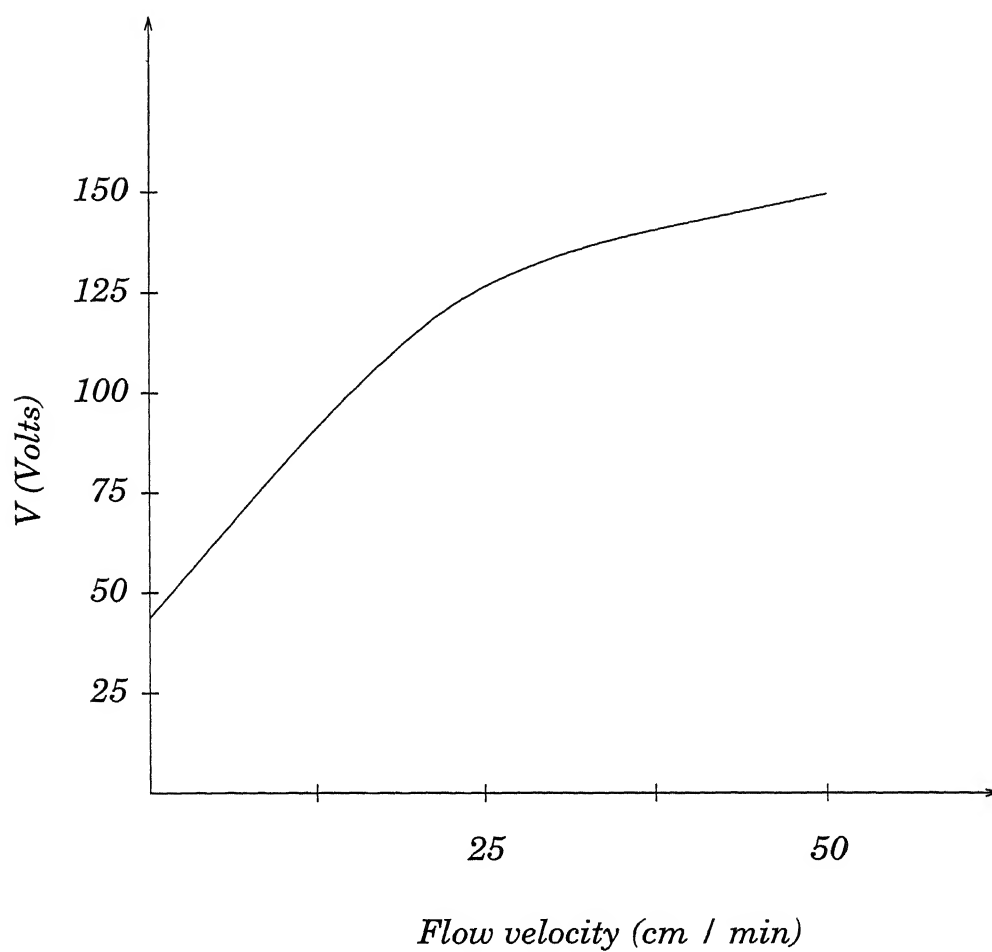


Figure 1.6: Effect of electrolyte flow on critical voltage(Allesu)

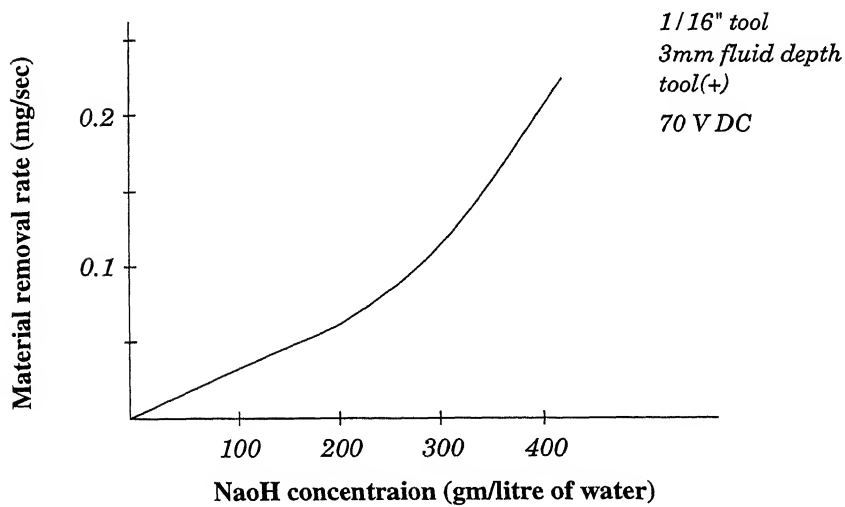
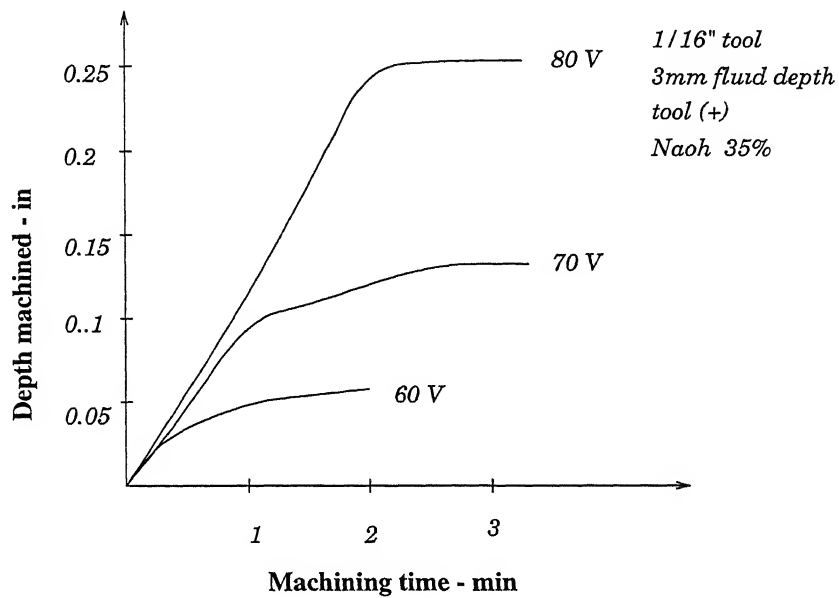


Figure 1.7: Graphs showing limited machining and effect of electrolyte concentration (Cook et al.)

Surface tension force, buoyant force and force due to gravity were identified as the factors influencing ECD thermocouple welding.

1.5 Objective and scope of present work

The objectives and scope of present work are given below

- To investigate the feasibility of Electrochemical discharge microwelding
- To develop a setup to produce V-welds in thin plates
- To establish the range of parameters in which satisfactory welding occurs
- To arrive at an optimum range of variables depending upon the strengths of the welds

Because of the limited time available only welds along straight seams were investigated. Also no metallurgical study was performed. Although different power supply were available for Electrochemical discharge process only smooth DC was used, as it was found to give good results in the earlier investigations on ECD microwelding of thin wires.

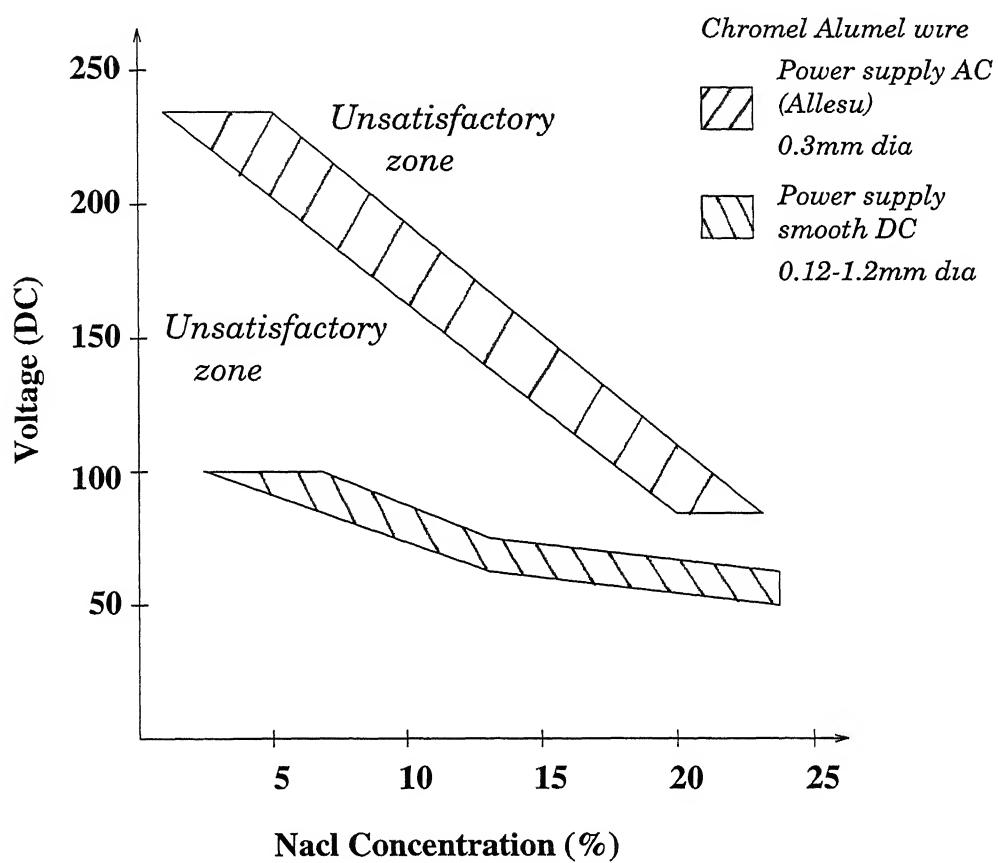


Figure 1.8: Voltage Vs Electrolyte concentration in microwelding

Chapter 2

PILOT EXPERIMENTS

2.1 Basic schemes

Three different approaches were tried out to effect ECD microwelding. The feasibility of all these methods were then studied by conducting some pilot experiments. The three methods that were the focus of attention are listed below

- Use of wire itself as an electrode
- Use of nozzle as an electrode and feeding the wire through the nozzle
- Treating the electrode and wire as separate entities and feeding the wire between the electrode and the plate

2.1.1 Use of wire itself as electrode

This arrangement is shown in Fig 2.1 . Here the wire is made the cathode and is connected to the negative terminal of the power supply. When the supply is given sparking occurs at the underside of the electrode. The objective here

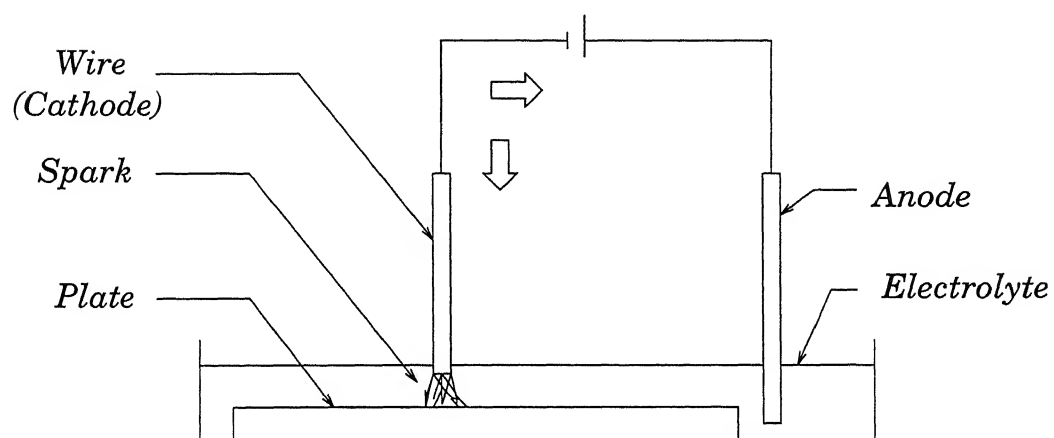


Figure 2.1: Figure showing use of wire as cathode

is to use the heat of the spark to melt the electrode as well as the baseplate so that deposition in the form of weld takes place. The wire is fed at the same speed as that of its melting rate. At the same time it is also traversed in the horizontal direction. The main advantage of this method is that welds in both x-direction and in y-direction can be made easily by traversing the wire or the table appropriately. But in this work welds only in the x-direction was tried out. Two low melting point wire materials, copper and brass were tried out and the basemetal was taken as brass. Different experiments were conducted with NaCl and HCl as electrolytes with various concentrations. The main problem with this method is that the wire frequently touches the basemetal. When this occurs, the basemetal will begin to act as the cathode as this is equivalent to connecting it to the negative terminal of the power supply. So there was no possibility of welding to take place.

2.1.2 Use of nozzle as an electrode

This arrangement is shown in Fig 2.2 . Here a nozzle was used and the wire was fed through it. A mild steel nozzle was connected to the negative terminal of the power supply thus making it the cathode. When supply is given sparking occurs on the underside of the nozzle. The nozzle was kept close to the baseplate so that the spark melts both the wire and the plate. One of the main problems encountered in this method is the task of insulating the hole present in the nozzle. It was found that the wire has a tendency to melt and weld itself to the nozzle, due to the spark. So the wire should not be allowed to touch the nozzle as it is fed through it. The diameter of the hole is very small of the order of 0.8 to 1.0 mm. (actually this diameter is very large since the diameter of the wire used is 0.06mm). But practically drilling such a fine hole was found to be impossible. Different methods were tried out to insulate it. Chemical deposition methods, which are widely used to deposit thin films

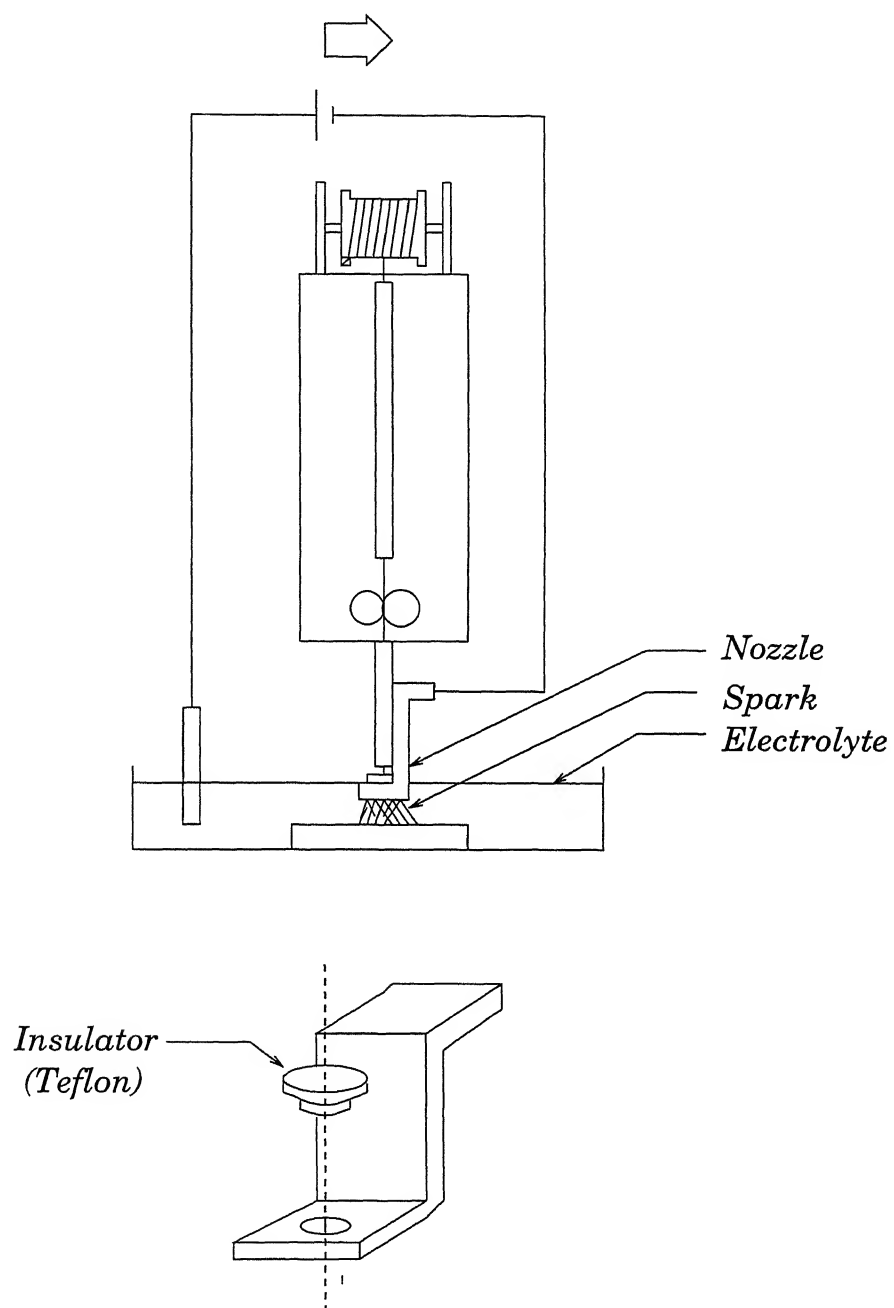


Figure 2.2: Figure showing arrangement with nozzle

on surfaces was ruled out as they cannot be used to deposit insulators. Insulation with a small guide made of teflon and having a shape as shown in the Fig 2.2 was tried out and was found to be partially successful. Here again the difficulty is compounded by the fact that teflon cannot be fastened to a surface by any adhesive. Special chemical methods are being used in industries to achieve this. But spot welding was found to be successful as long as the teflon piece stayed in its place. investigations were not carried further as the aim of the thesis is to get seam welds only. It was also found that the life of the nozzle is very short as the sparks melts and deform the nozzle. The nozzle can be designed with high melting point materials like tungsten, which again poses the question of machinability. So if the twin problem of fabricating a nozzle of suitable dimensions with some high strength material and insulating the hole in the nozzle with a high melting point material can be addressed, this method can be tried out for seam welding also.

2.1.3 Treating the wire and nozzle as seperate entities

This configuration is shown in Fig 2.3 . Here the electrode is kept vertical and the wire is fed under the electrode. As was stated earlier the sparking occurs at the underside of the electrode. Also since welding takes place under the electrolyte (a liquid medium), very little time is available for welding to take place. So the wire has to be fed accurately so that it is in contact with the plate when the sparking occurs. This scheme has been found to be practical and produced satisfactory welds during the pilot experiments. So this scheme was adopted for further detailed experiments.

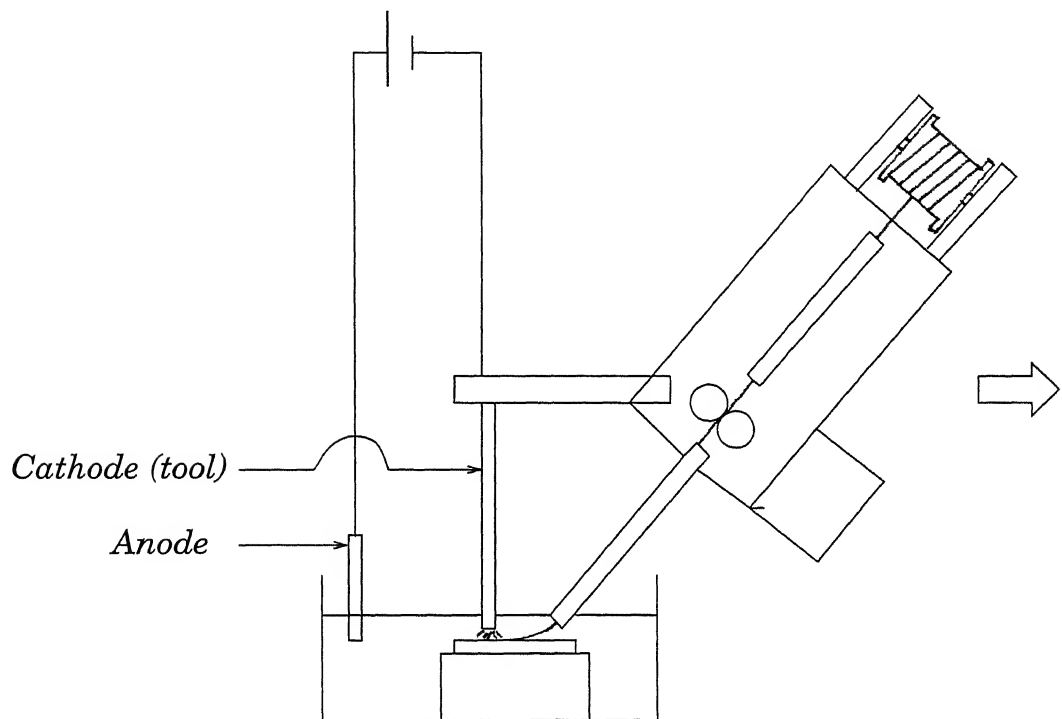


Figure 2.3: Diagram showing arrangement with wire and electrode as separate entities

Chapter 3

EXPERIMENTAL SET UP

3.1 Development of experimental set up

The experimental set up is divided into two parts - electrical and mechanical. The electrical part consists of the circuit and the associated parts to produce smooth DC. The mechanical part contains the feeding and traversing mechanisms as well as the electrochemical bath. The photograph of the setup is shown in Fig 3.1 and Fig 3.2. The line diagram is shown in Fig 3.3. The detailed diagram is shown in Fig 3.4 to Fig 3.16. The various components are discussed below.

3.1.1 Electrical part

The power supply was taken from the A.C. mains and controlled using a variac. It was then stepped down using a transformer, rectified using a bridge rectifier and connected to the electrodes through a variable inductance. Inductance and capacitance play a major role in the circuit. It was found by Basak[1], that the inclusion of capacitance and inductance in the circuit was found to increase the discharge frequency and intensity drastically. Also the inclusion of

inductance limits the steep drop in the current flowing through the circuit. Since high frequency and discharge are needed for good microwelding, these were included in the circuit. The current and voltage in the circuit was measured with a ammeter and voltmeter respectively. This can be varied by using the variac.

3.1.2 Mechanical part

In the experiments V welds of two thin brass plates (0.15mm) were obtained. A thin copper wire of diameter 0.06mm was used to weld these plates. So a suitable mechanism for feeding the wire as well as traversing it was needed. The wire was guided through a mild steel tube. The ends of the tube were insulated using teflon. The wire was then fed between two rollers. The rollers were also insulated using teflon. The rollers were driven using a stepper motor. Drive was given to a single roller while the other was left idle. Contact between the two rollers was maintained using a spring. Motor used for feeding was a SRI-SYN motor with 10 Kgcm torque working on 6V DC while that for traversing was a SRI-SYN motor with 3Kgcm torque working on 6V DC. It was found that the distance between the two electrodes did not have any effect on the discharge phenomenon. Hence their relative positioning do not influence the microwelding process. Dilute Hydrochloric acid was taken as the electrolyte in all experiments. The reason for choosing Hcl is that it is a strong acid. A strong electrolyte ionises readily and hence they have more ions for conduction. This in turn results in easy production of discharge and increased intensity of spark. Also high conductivity of the electrolyte results in more heat being conducted to the plates through the electrolyte, facilitating the microwelding process. Copper was taken as the cathode, since it is a good conductor and graphite was taken as the anode.

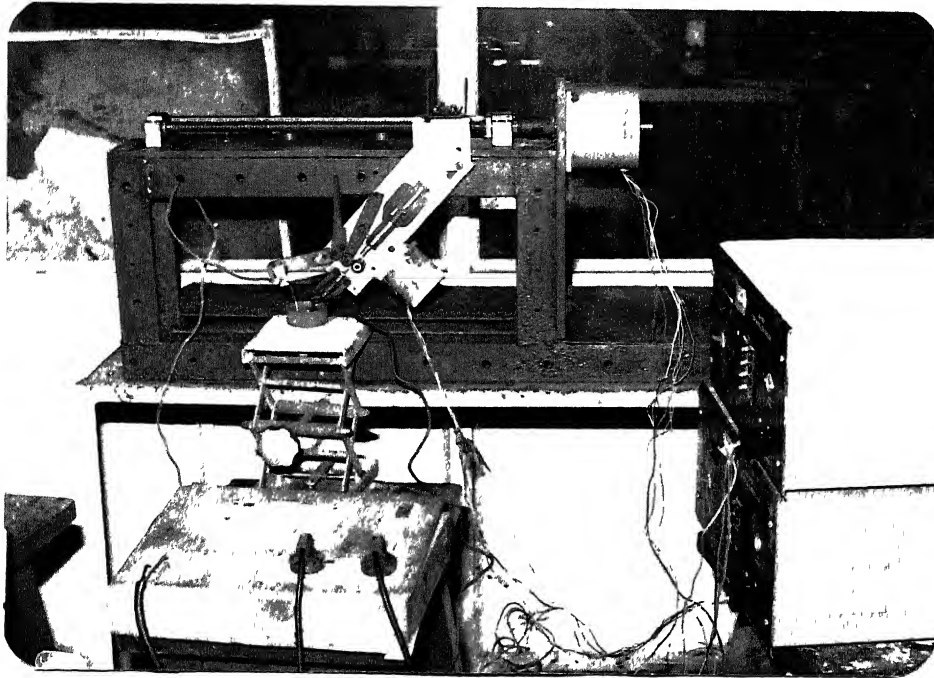


Figure 3.1: Photograph of experimental setup

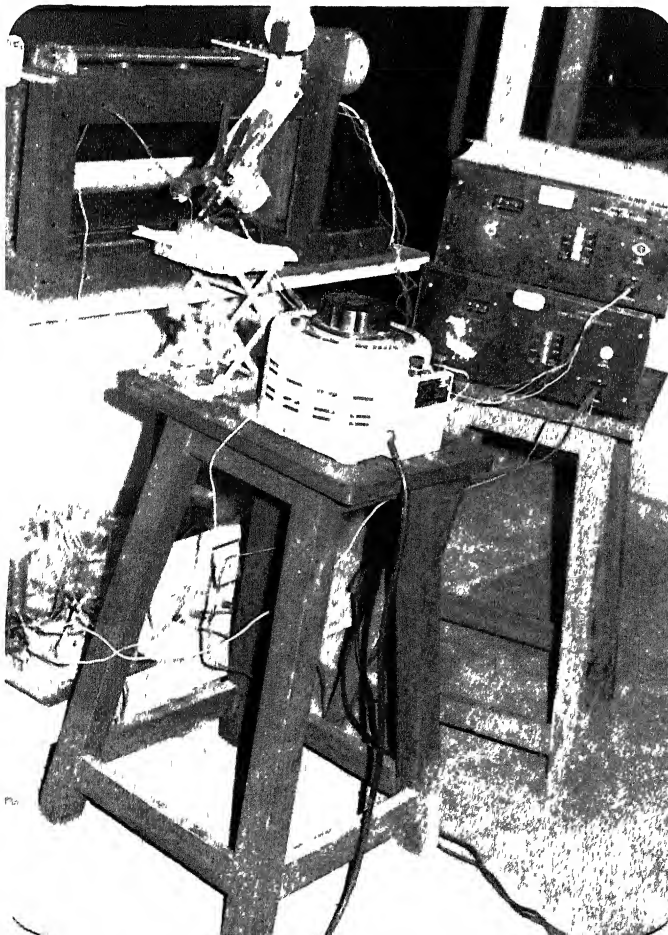
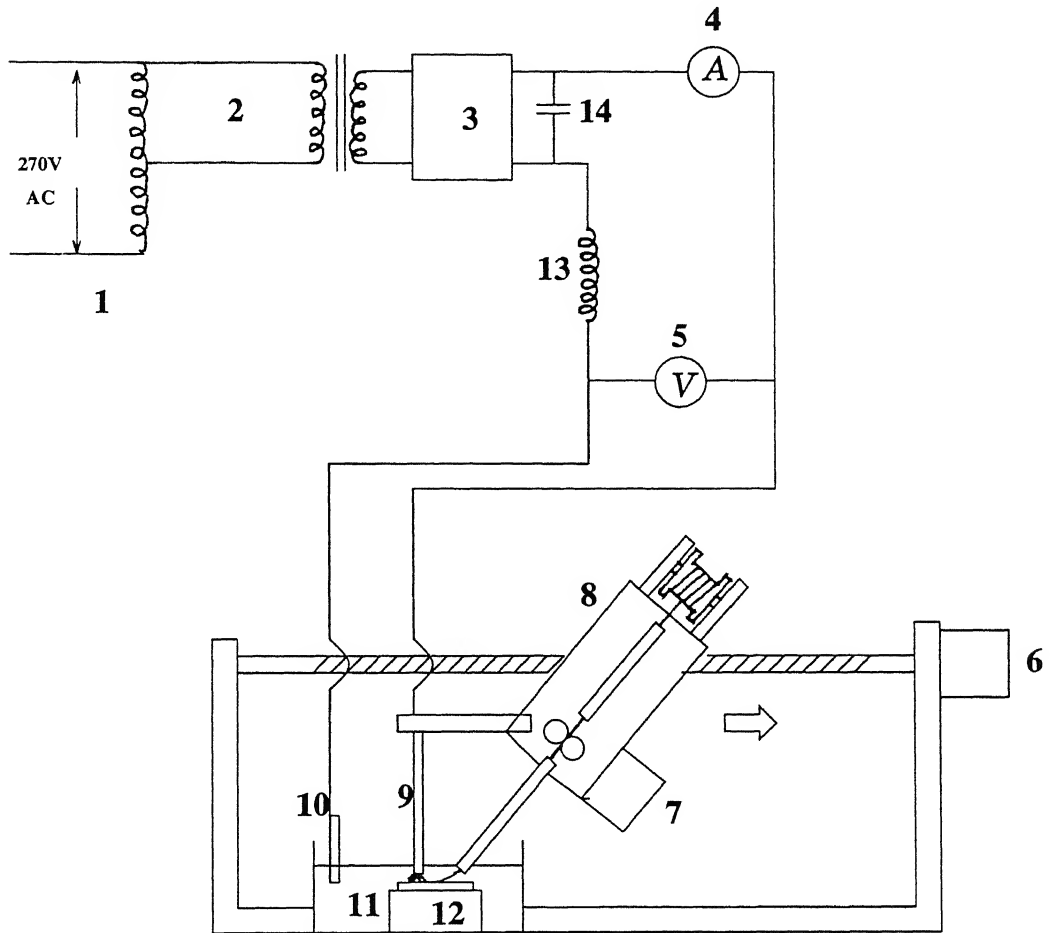


Figure 3.2: Photograph of experimental setup



1-Variac, 2-Step down transformer, 3-Bridge rectifier, 4-Ammeter(0-5 Amps), 5-Voltmeter (0-200 V), 6,7-Motors, 8-Feeding arrangement, 9-Tool(cathode), 10-Anode, 11-Electrolyte(Hcl), 12-workpiece with fixture, 13-Inductance, 14-Capacitance

Figure 3.3: Line diagram of experimental setup for ECD microwelding

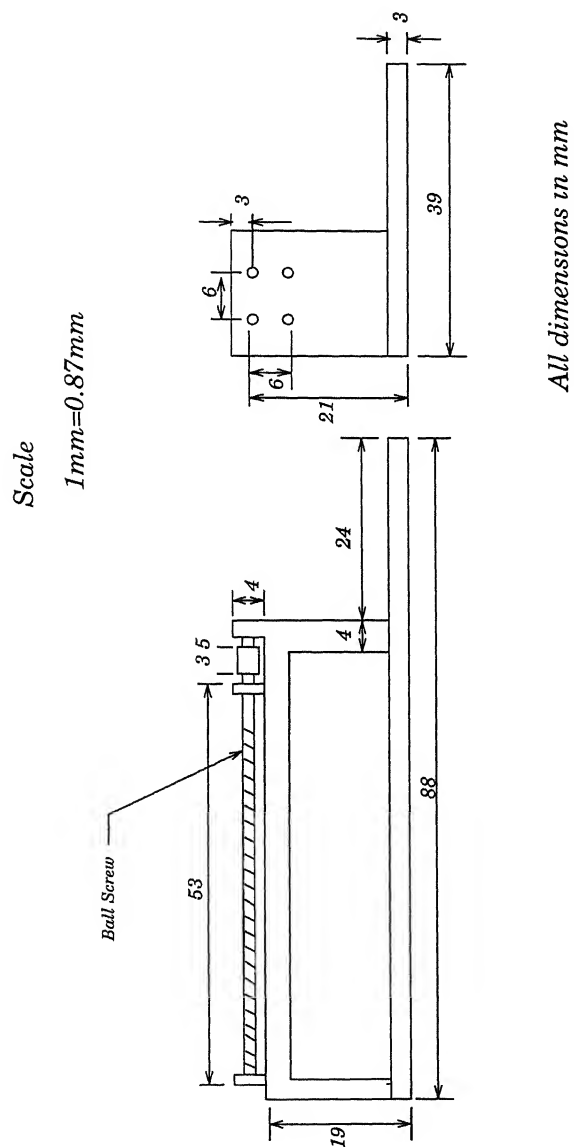


Figure 3.4: Base

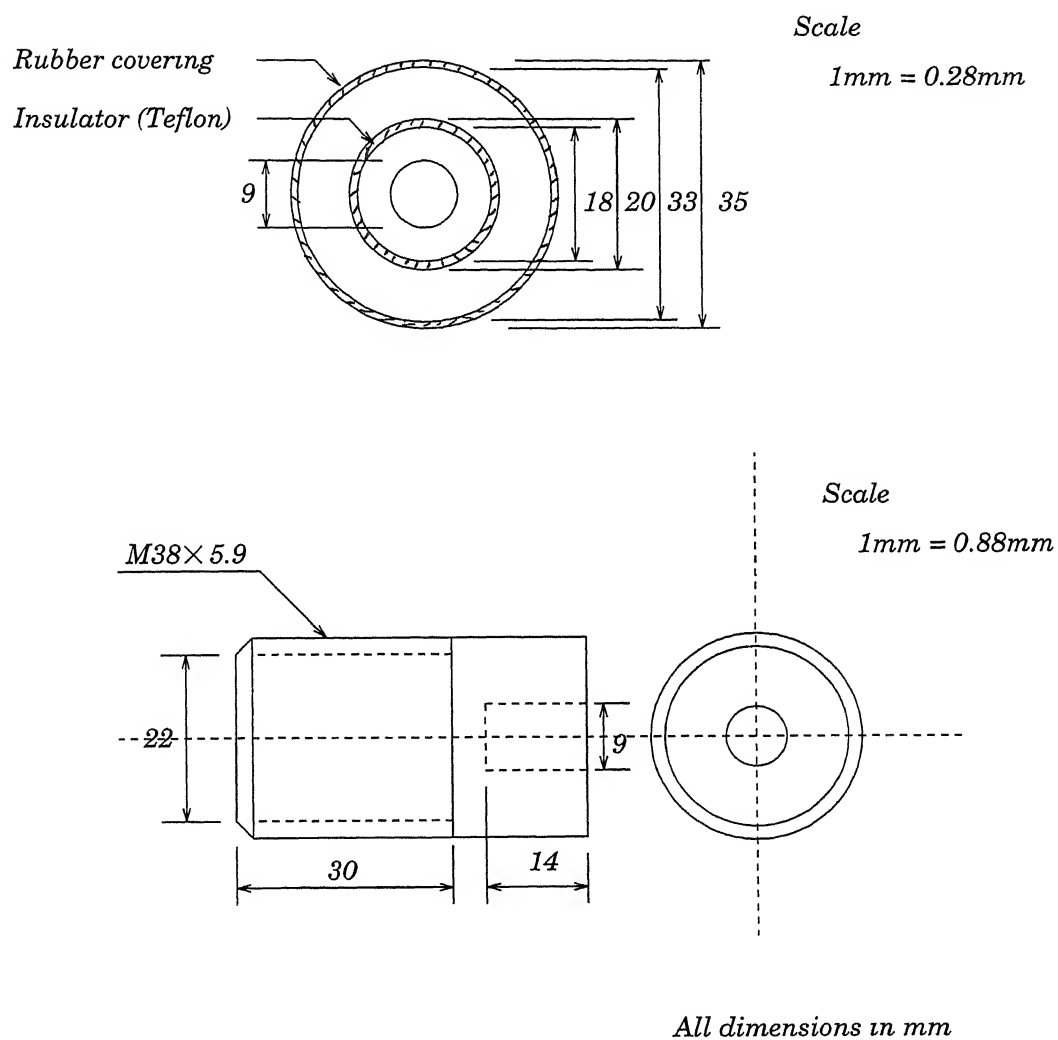


Figure 3.5: Roller and threaded shaft

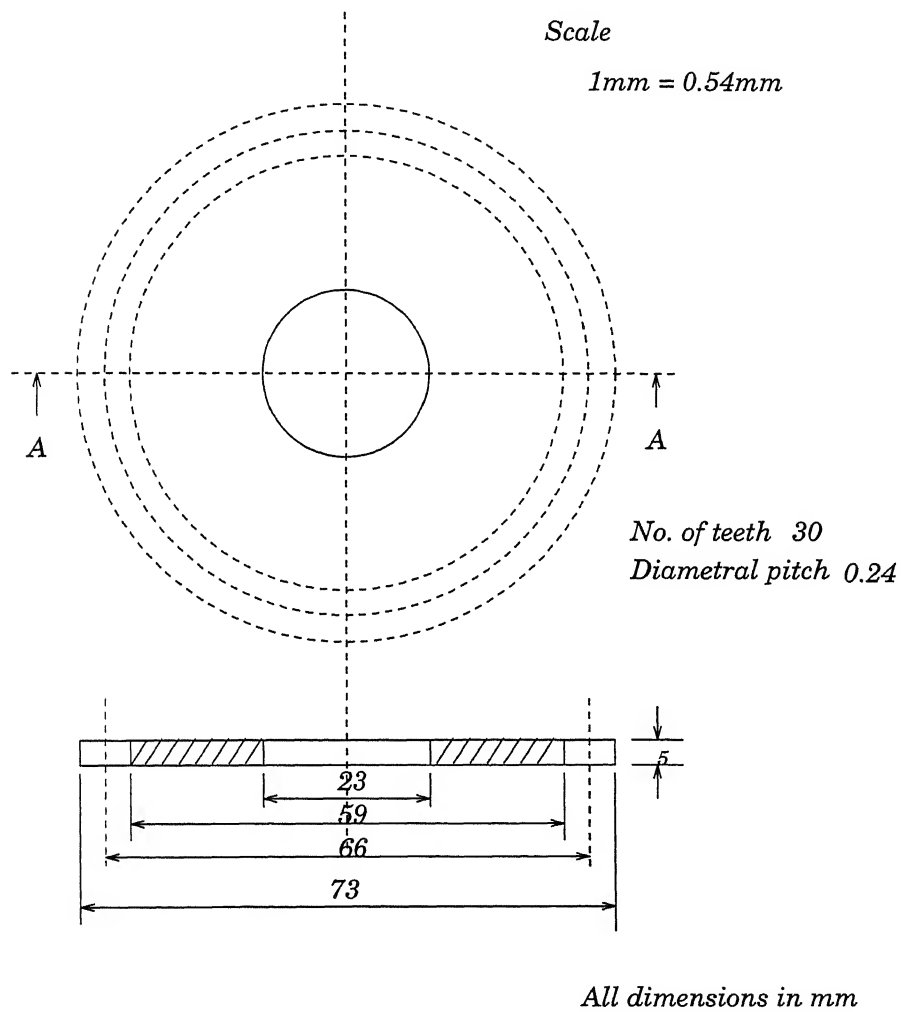


Figure 3.6: Spur gear

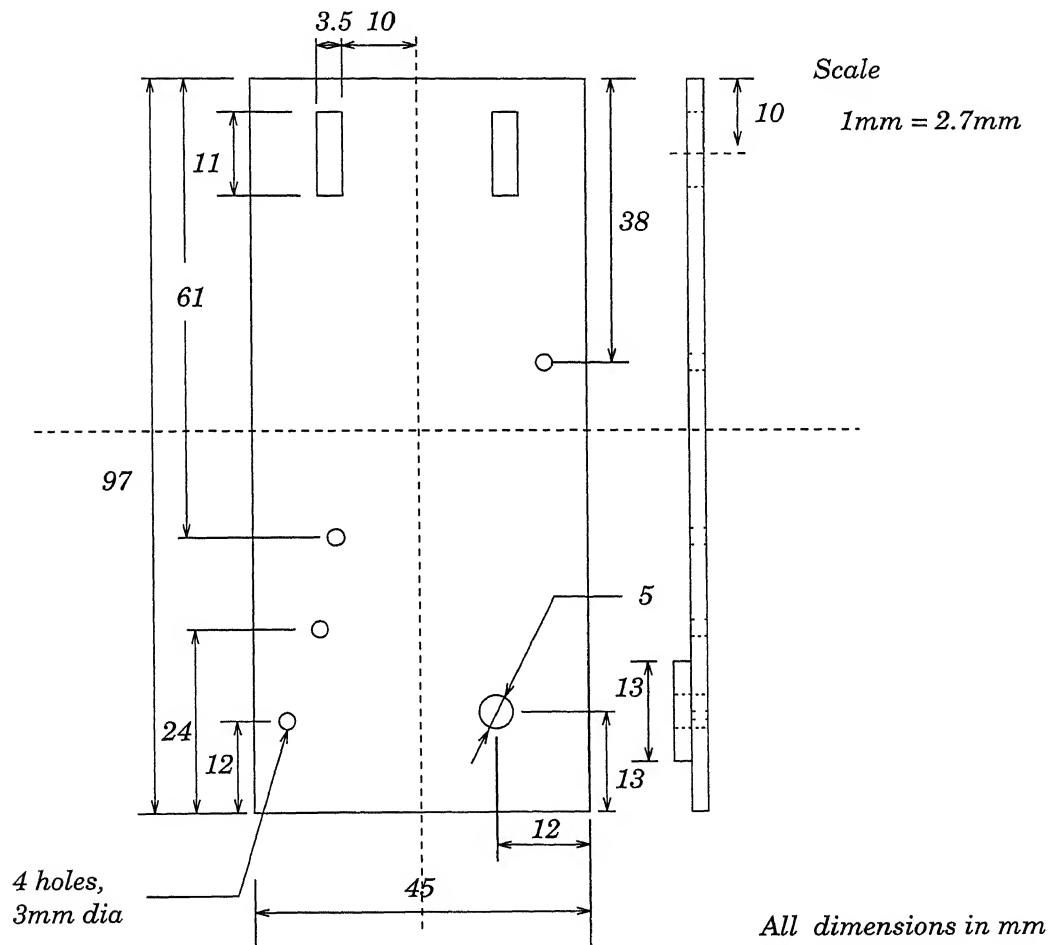


Figure 3.7: Diagram of main plate

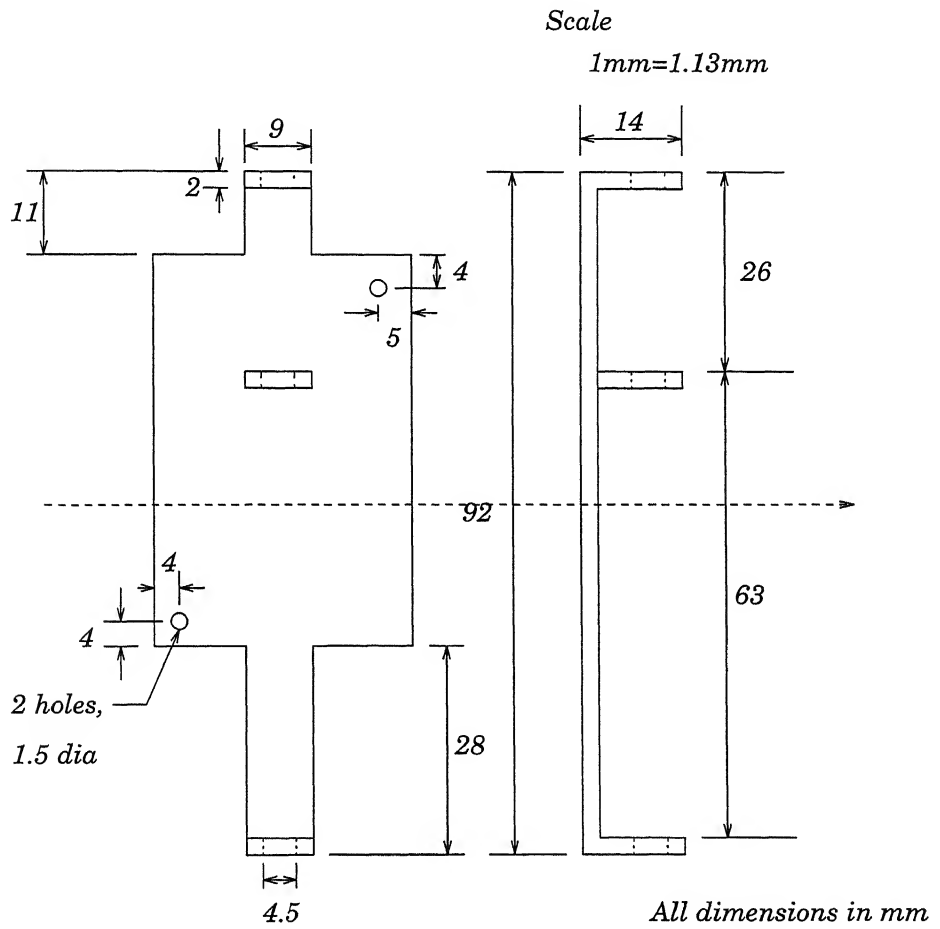


Figure 3.8: Diagram of guide holder

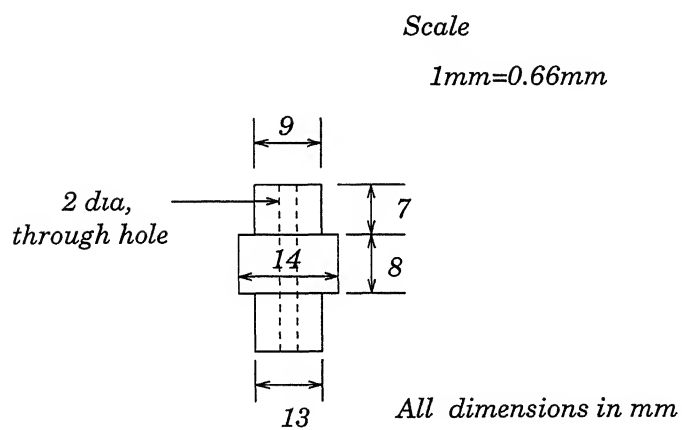


Figure 3.9: Teflon piece

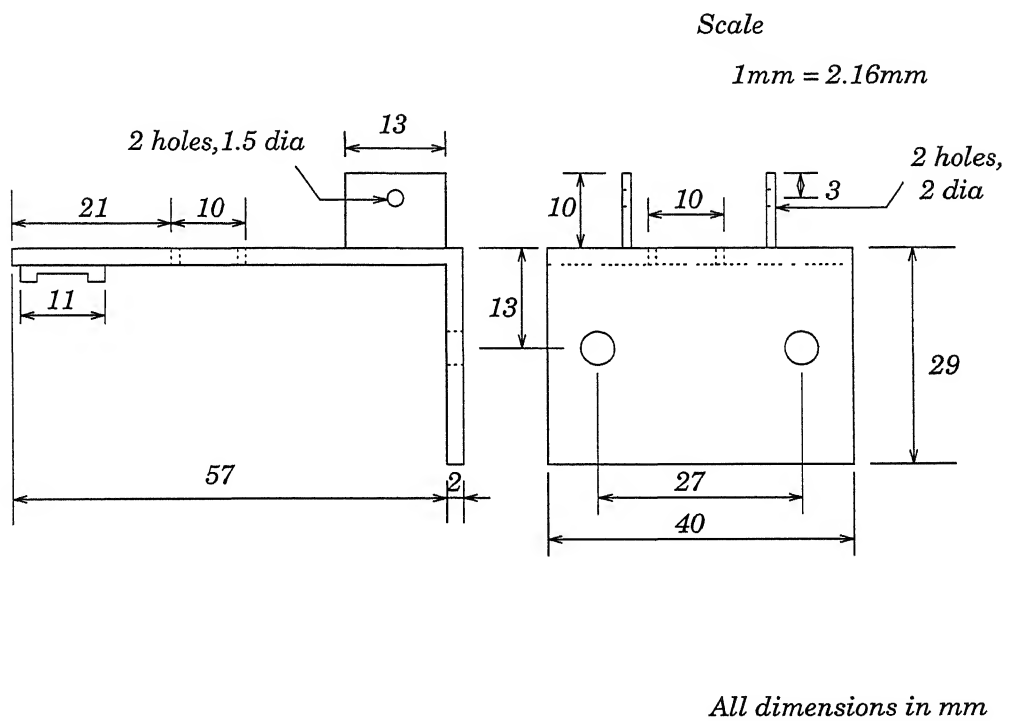


Figure 3.10: Diagram of bracket

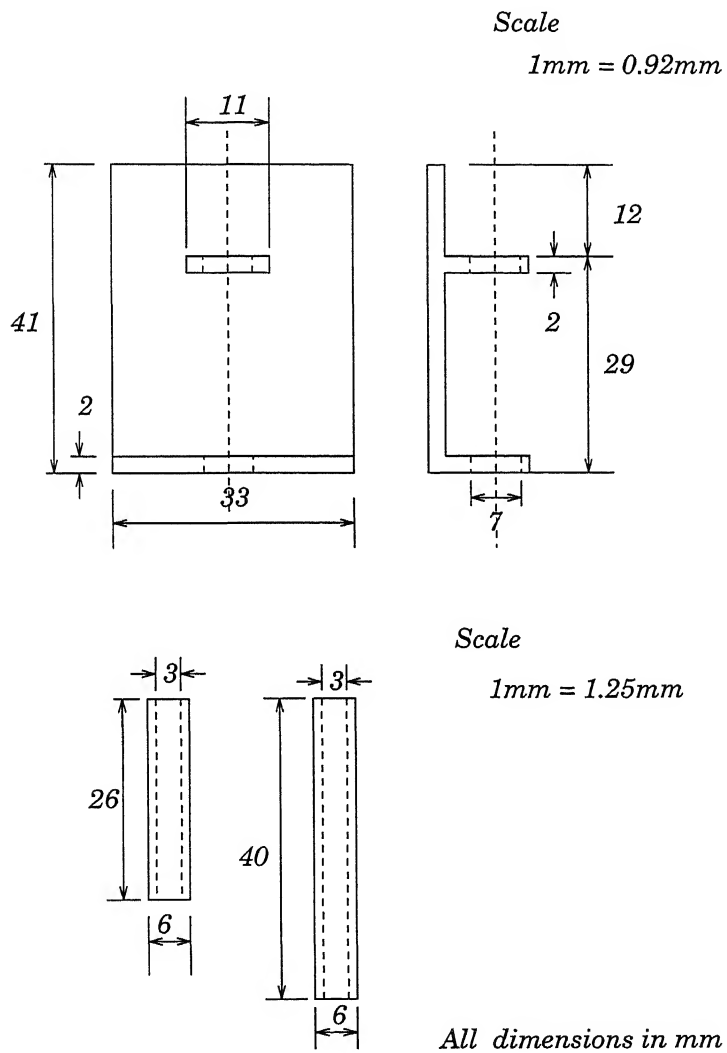


Figure 3.11: Diagram of guide holder and guide

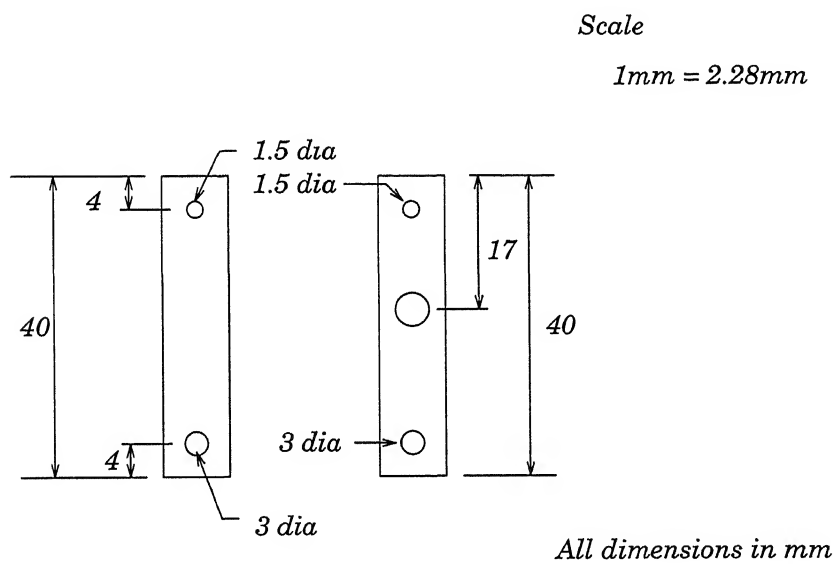


Figure 3.12: Diagram of roller holder

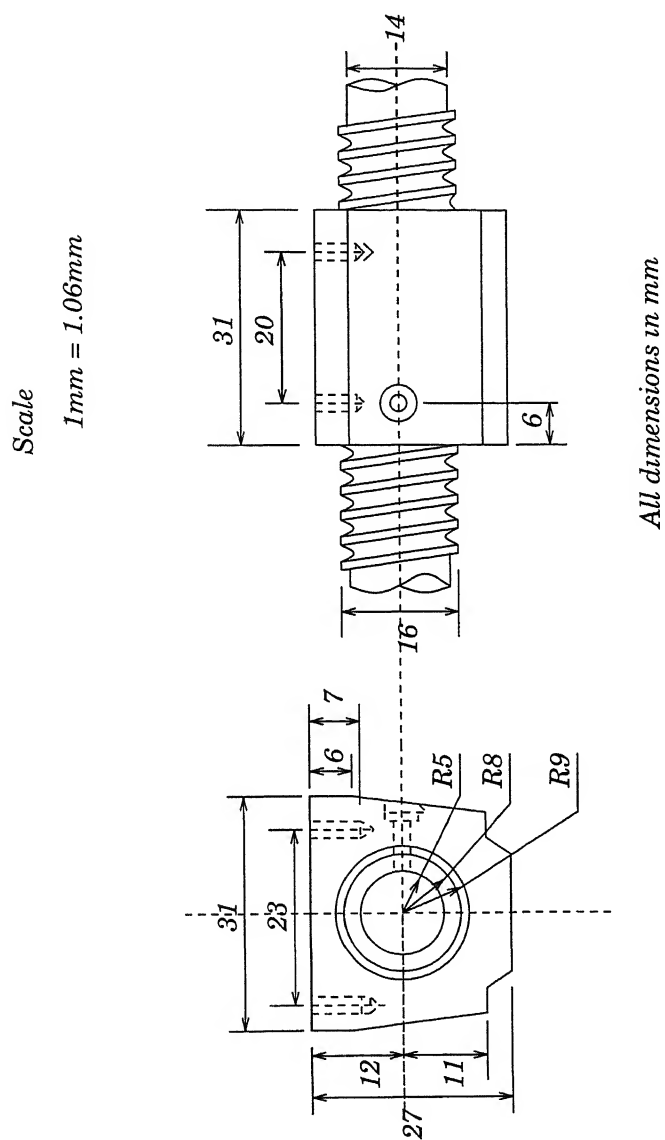


Figure 3.13: Diagram of ball screw

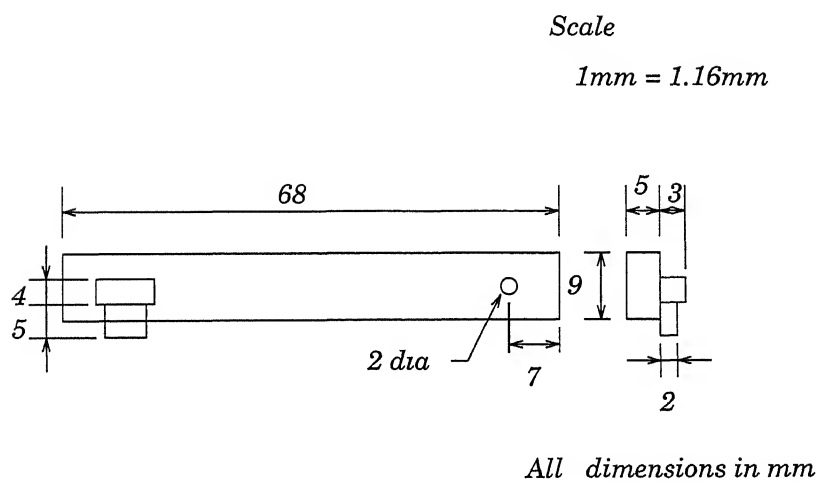


Figure 3.14: Diagram of electrode holder

Chapter 4

EXPERIMENTAL INVESTIGATION OF ECD MICROWELDING

4.1 Introduction

As was already stated ECD process was widely used for machining. Limited work has been done in the field of ECD welding. Allesu[2] has done some experiments on ECD welding of thermocouples. Detailed work in ECD thermocouple welding was done by Parija[6]. In the present work the feasibility of using ECD process for welding of thin plates was studied. It was found from the work of Sarmistha Parija that welding can be performed only in a very narrow zone of voltage and concentration. Therefore the objective of the present work is to find out this range for ECD welding of thin plates and to establish the effects of voltage, concentration of electrolyte, inductance and tool-workpiece gap on the micro welding process.

4.1.1 Design of experiments

The first step was to find a wire of suitable material and size for performing experiments. Since the energy of the sparks are low, the wire must have as small a diameter as possible and must have reasonably low melting point. After many trials copper wire of 0.06mm diameter was chosen. Experiments were conducted with plates of various materials and thicknesses. Finally brass plate of 0.15mm thickness was chosen.

Initially experiments were performed without the workpiece to study the characteristics of the Electrochemical Discharge process. Experiments were conducted with and without inductance. They were found to follow the conventional trend in that the fall in current as the spark occurs is more steep if an inductance is not present in the circuit.

The workpiece was taken as a brass plate of thickness 0.15mm. Brass was chosen because of its low melting point (850 degrees centigrades) A very thin copper wire of diameter 0.06mm was used to weld the two plates together. Experiments were conducted with four different electrolyte concentrations (15%,20%,25% and 30% HCl). Inductance was also varied in four stages (0mH,30mH,45mH,90mH) to determine its effect on the process. The electrolyte was replenished at regular intervals of one minute.

The length of the plates to be welded was taken as 5mm. The edges were filed and a V groove was made. They were then clamped tightly. The wire was fed at the interface and welding performed. Experiments were performed by first keeping the inductance at a particular value. Then the concentration of the electrolyte was fixed . Then for a particular voltage the gap between the electrode (cathode) and the plate is varied to obtain welds. The voltage with which satisfactory weld occurs was then found out. Then that voltage was kept constant and the gap was varied. This was done to find out the gap

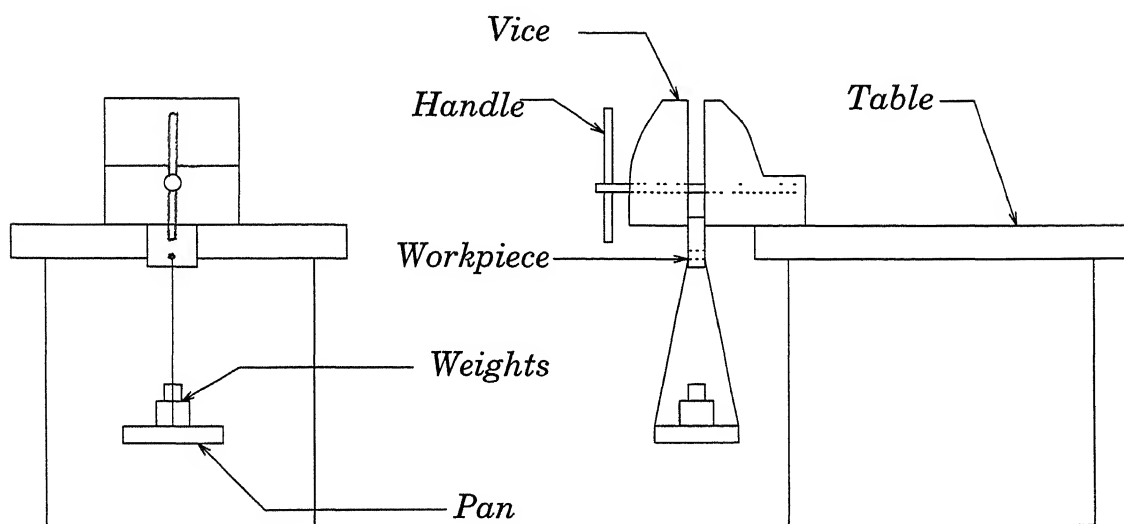


Figure 4.1: Diagram showing scheme for testing welds

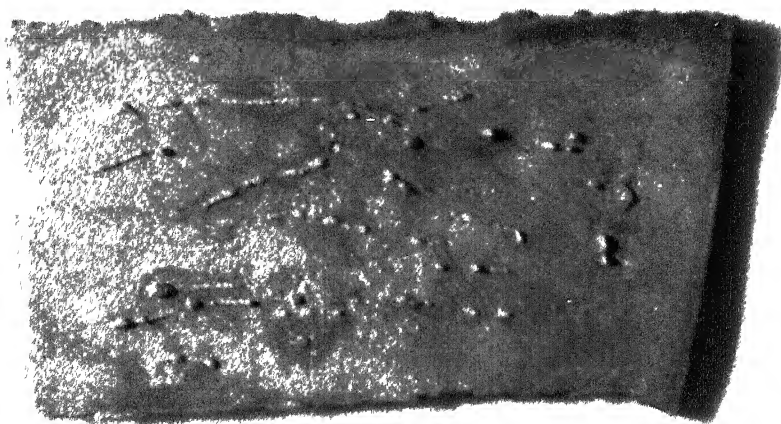


Figure 4.2: Photograph of welds

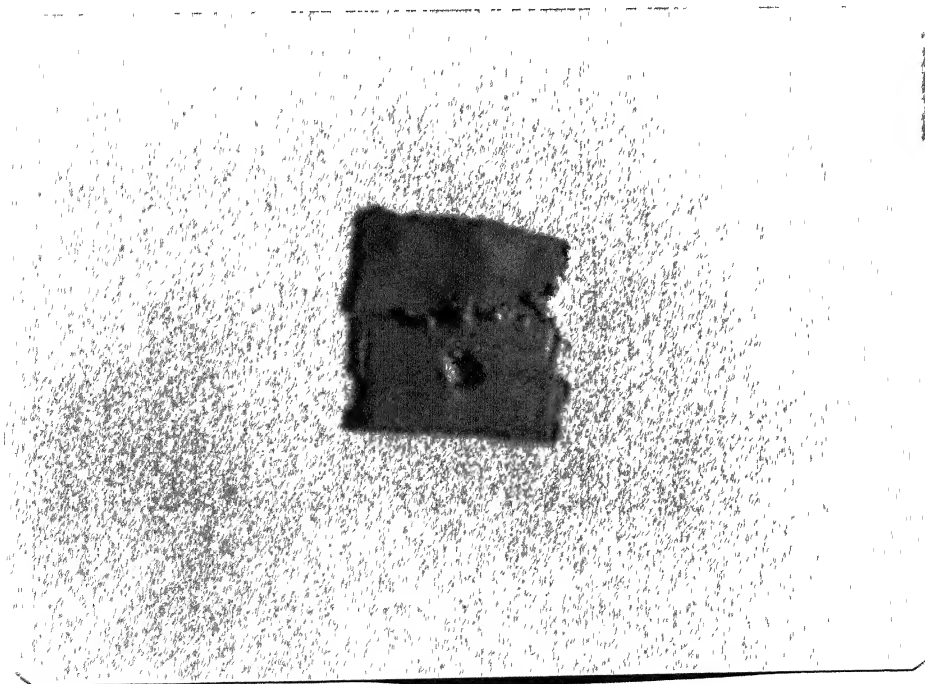


Figure 4.3: Photograph of weld

range at that particular voltage. This was then repeated for various voltages. The welds that were obtained during this experimentation were preserved for testing. Then the concentration was changed and the whole process repeated. This gave the voltage and gap ranges with a particular inductance. The welds obtained are shown on the previous page. After this the inductance was changed to the next higher value and the whole set of experiments was repeated. Finally the strengths of the welds were tested by suspending weights. The scheme used for testing the strengths is shown in Fig 4.1. The workpiece was held between the jaws of a vice and then clamped tightly. Then weights were added on a pan which was suspended from the welded workpiece as shown in the figure. The weight at which the weld breaks was noted. This weight was then divided by the total length of the weld to give the strength of the weld.

With these data the following graphs were drawn.

- Voltage Vs Concentration at various inductance values
- Gap Vs voltage at various inductance values
- Strength Vs Concentration at various inductance values
- Maximum strength Vs Concentration at various inductance values

4.2 Results and Discussions

4.2.1 Effect of concentration on voltage

The critical voltage above which welding occurs is shown in the Table 4.1 for different concentration and inductances. This graph is shown in Fig 4.4 It can be observed from the graph that in all cases the voltage at 15% concentration

is greater than that at 30%. This can be attributed to the increase in conductivity of the electrolyte at higher concentration. The voltage remains constant between 20% and 25% concentration. The voltage at 30mH is greater than that at 45mH. Also the voltage at 45mH is lesser than that at 90mH. This may be because at low inductance the intensity of the discharge is low and hence higher voltage must be applied. But at higher inductances the power dissipated is so high that the gap must be increased, resulting in more heat loss to the electrolyte. Hence the critical voltage increases. At 45mH it is between these two cases. In the case of 30% concentration, the conductivity increases and hence the voltage for 30mH and 45mH are same. This may suggest that an optimum inductance exists between 30mH and 90mH.

4.2.2 Effect of voltage on gap

The data for this is given in Table 4.2, Table 4.3 and Table 4.4. The effect of voltage on the gap is shown in Fig 4.5 to Fig 4.16 for different concentration and inductance values. It was expected in the beginning that the gap range is going to be very small. This was true in the case of microwelding by Parija[6]. The gap ranges obtained only confirms this. It can also be seen that the lower and upper limits of the gap increases as the voltage increases. This is expected because a higher voltage delivers sparks of high intensity. Hence the gap should be increased accordingly. Another important observation is that the gap range is much larger in the case of 30 mH than in other cases. This suggests that the optimum inductance is very close to 30 mH although the critical voltage at which welding starts is greater compared with 45mH and 90 mH. These results show that accurate control of the gap is necessary for microwelding. It would be better to install a servo mechanism to constantly monitor and control the gap as the welding occurs. This was not tried out in this work due to lack of time and infrastructure.

| Inductance | Concentration | Voltage range |
|------------|---------------|---------------|
| 30 mH | 15% | 105V-107.5V |
| | 20% | 102.5V-107.5V |
| | 25% | 102.5V-107.5V |
| | 30% | 97.5V-107.5V |
| 45 mH | 15% | 102.5V-107.5V |
| | 20% | 100V- 107.5V |
| | 25% | 100V-107.5V |
| | 30% | 97.5V- 107.5V |
| 90 mH | 15% | 105V-107.5V |
| | 20% | 100V-107.5V |
| | 25% | 100V-107.5V |
| | 30% | 100V-107.5V |

Table 4.1: Relationship between voltage and concentration at various inductances

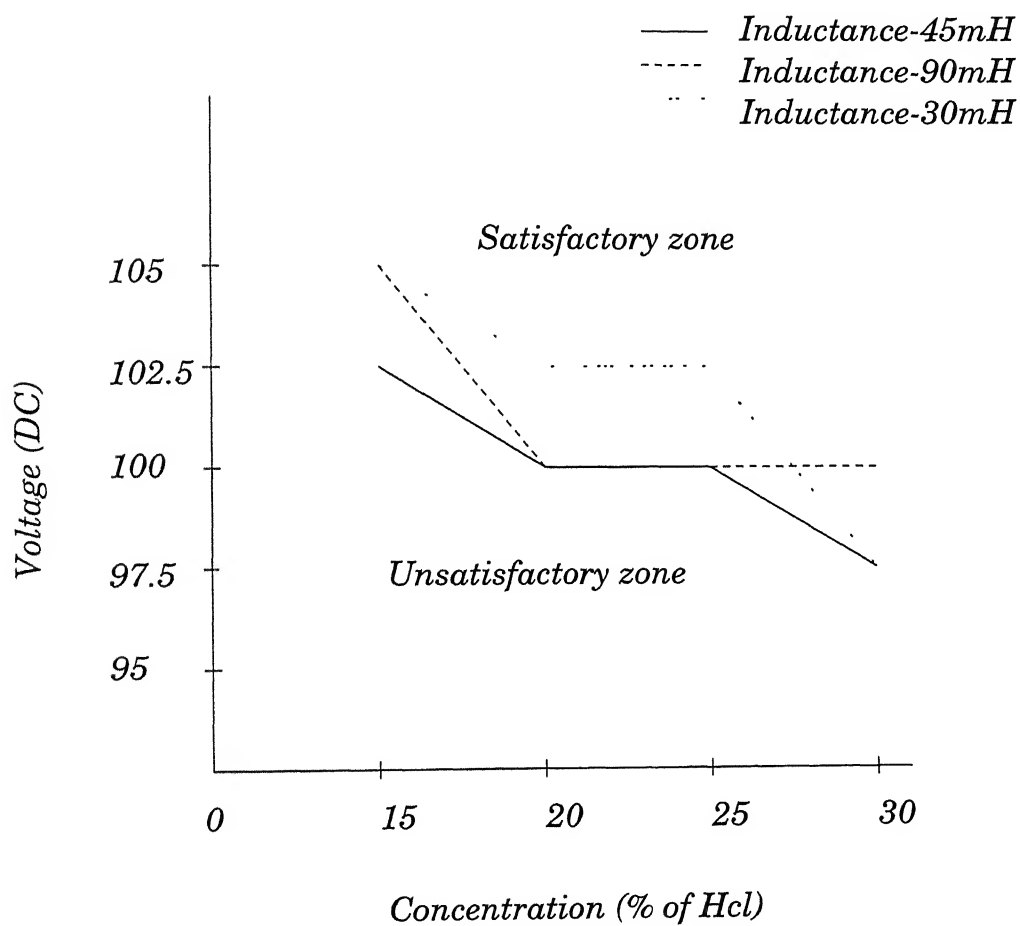


Figure 4.4: Effect of concentration on voltage

| Inductance | Concentration | Voltage range | Gap(mm) | Strength (Kg/mm) |
|------------|---------------|---------------|---------|------------------|
| 30 mH | 15% | 105V | 0.6 | 0.35 |
| | | | 0.8 | 0.55 |
| | | 107.5V | 0.8 | 0.1 |
| | | | 1.0 | 0.12 |
| | 20% | 102.5V | 0.7 | 0.65 |
| | | | 0.9 | 0.43 |
| | | 107.5V | 0.9 | 0.32 |
| | | | 1.3 | 0.4 |
| | 25% | 102.5V | 0.9 | 1.2 |
| | | | 1.2 | 0.88 |
| | | 107.5V | 1.3 | 0.56 |
| | | | 1.6 | 0.44 |
| | 30% | 97.5V | 1.3 | 0.9 |
| | | | 1.6 | 1.0 |
| | | 107.5V | 1.74 | 0.61 |
| | | | 1.8 | 0.33 |

Table 4.2: Table showing gaps and strengths at various voltages and concentration at 30mH

| Inductance | Concentration | Voltage range | Gap(mm) | Strength(Kg/mm) |
|------------|---------------|---------------|---------|-----------------|
| 45 mH | 15% | 102.5V | 0.24 | 0.23 |
| | | | 0.3 | 0.4 |
| | | 107.5V | 0.44 | 0.3 |
| | | | 0.46 | 0.6 |
| | 20% | 100V | 0.46 | 0.72 |
| | | | 0.52 | 0.3 |
| | | 107.5V | 0.52 | 0.7 |
| | | | 0.56 | 0.5 |
| | 25% | 100V | 0.52 | 0.25 |
| | | | 0.58 | 0.45 |
| | | 107.5V | 0.54 | 0.7 |
| | | | 0.58 | 0.3 |
| | 30% | 97.5V | 0.5 | 0.64 |
| | | | 0.54 | 0.5 |
| | | 107.5V | 0.58 | 0.8 |
| | | | 0.63 | 0.9 |

Table 4.3: Table showing gaps and strengths at various voltages and concentration at 45mH

| Inductance | Concentration | Voltage range | Gap(mm) | Strength(Kg/mm) |
|------------|---------------|---------------|---------|-----------------|
| 90 mH | 15% | 105V | 0.44 | 0.2 |
| | | | 0.5 | 0.25 |
| | | 107.5V | 0.52 | 0.2 |
| | | | 0.62 | 0.3 |
| | 20% | 100V | 0.46 | 0.43 |
| | | | 0.5 | 0.23 |
| | | 107.5V | 0.52 | 0.25 |
| | | | 0.64 | 0.4 |
| | 25% | 100V | 0.46 | 0.24 |
| | | | 0.54 | 0.32 |
| | | 107.5V | 0.54 | 0.35 |
| | | | 0.64 | 0.4 |
| | 30% | 100V | 0.48 | 0.67 |
| | | | 0.52 | 0.48 |
| | | 107.5V | 0.6 | 1.5 |
| | | | 0.72 | 0.9 |

Table 4.4: Table showing gaps and strengths at various voltages and concentration at 90mH

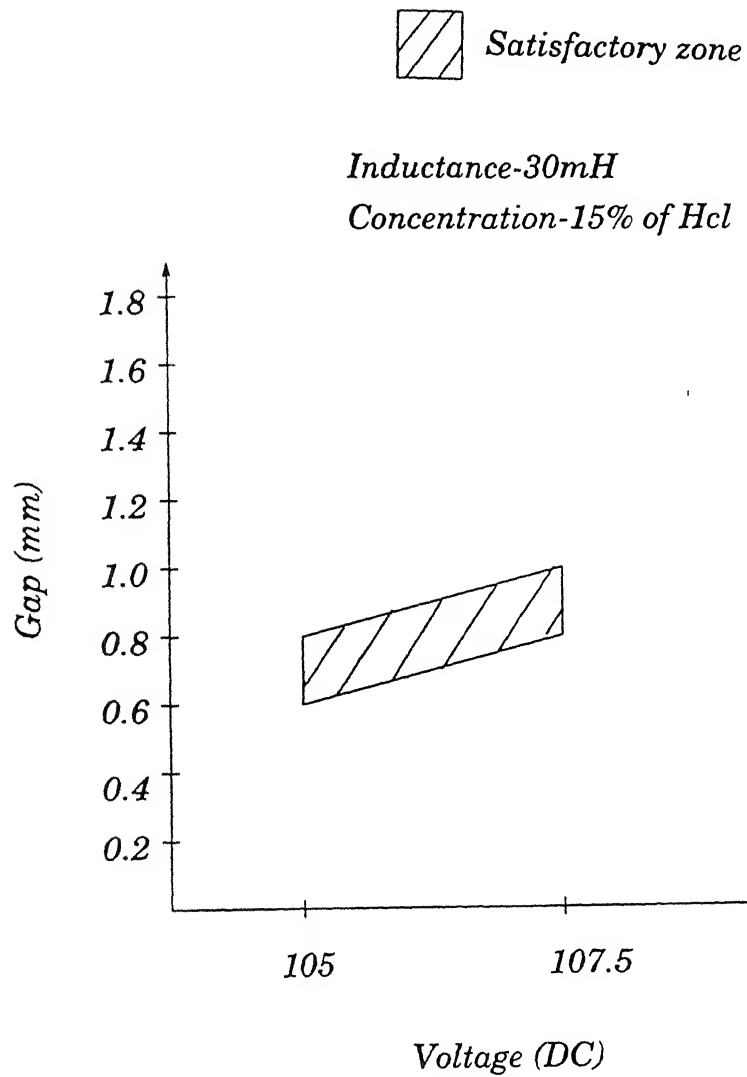


Figure 4.5: Relationship between voltage and concentration at 30mH and 15% concentration

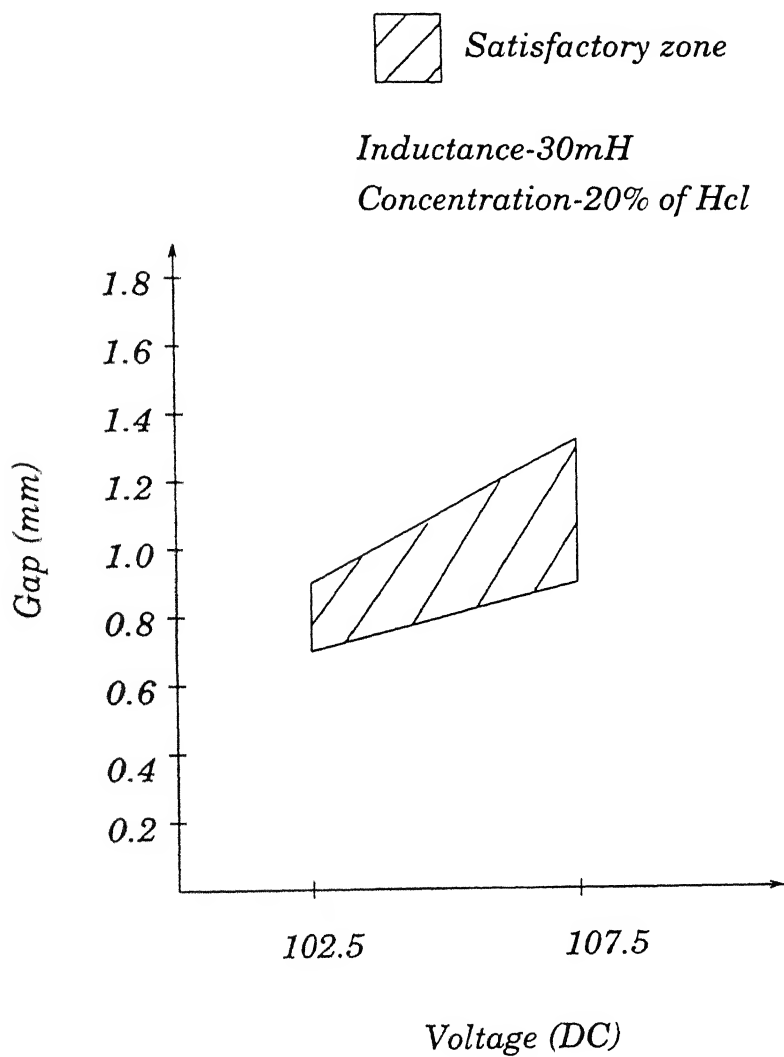


Figure 4.6: Relationship between voltage and concentration at 30mH and 20% concentration

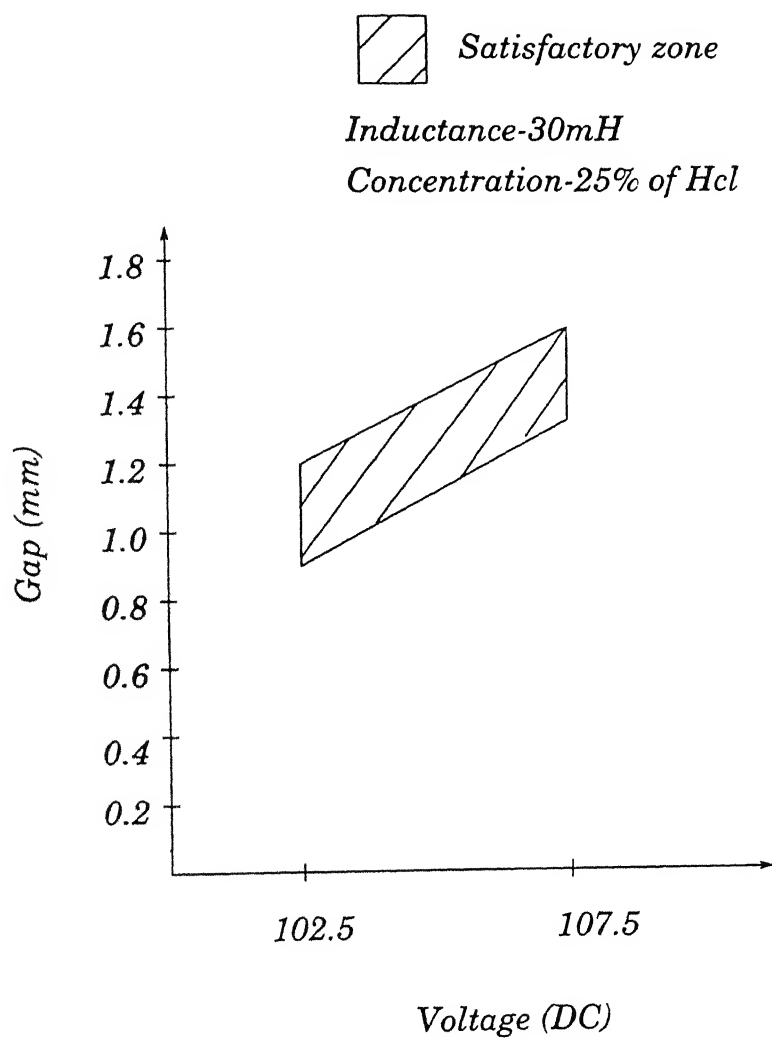


Figure 4.7: Relationship between voltage and concentration at 30mH and 25% concentration

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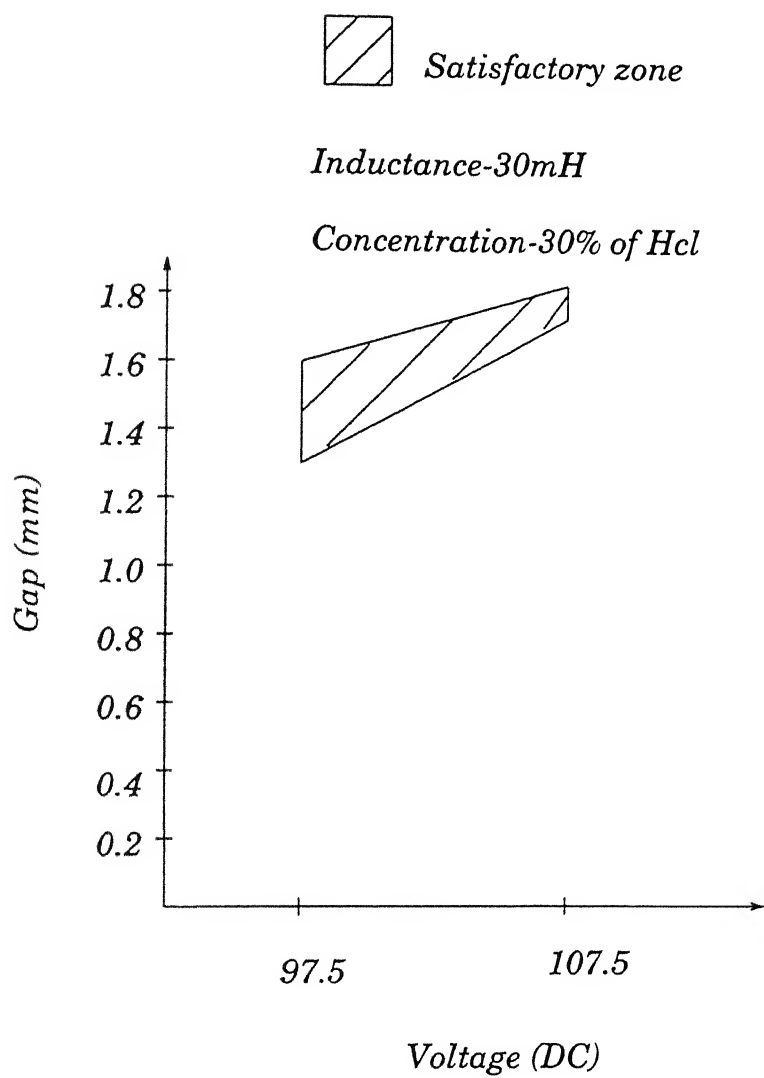


Figure 4.8: Relationship between voltage and concentration at 30mH and 30% concentration

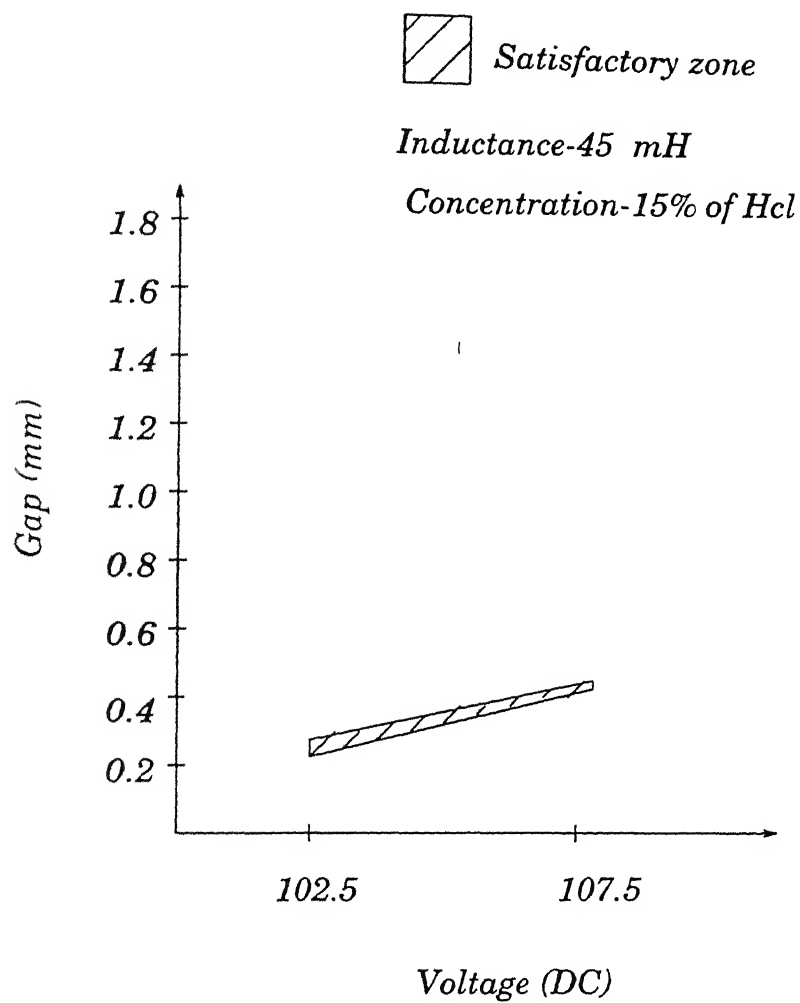


Figure 4.9: Relationship between voltage and concentration at 45mH and 15% concentration

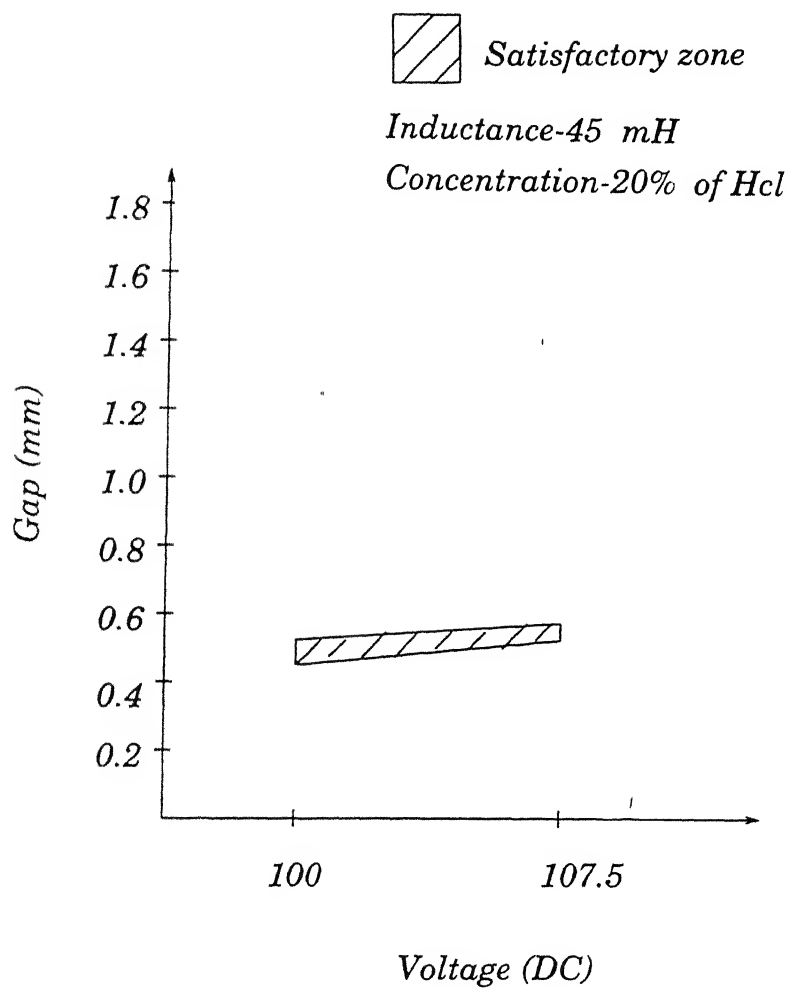


Figure 4.10: Relationship between voltage and concentration at 45mH and 20% concentration

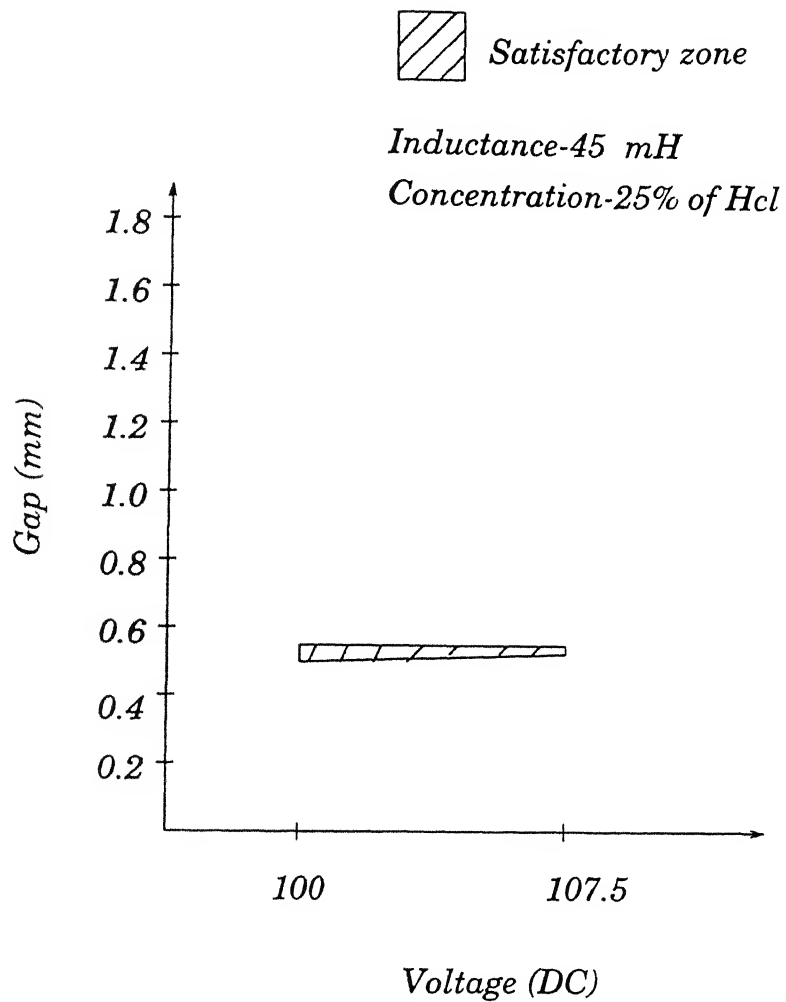


Figure 4.11: Relationship between voltage and concentration at 45mH and 25% concentration

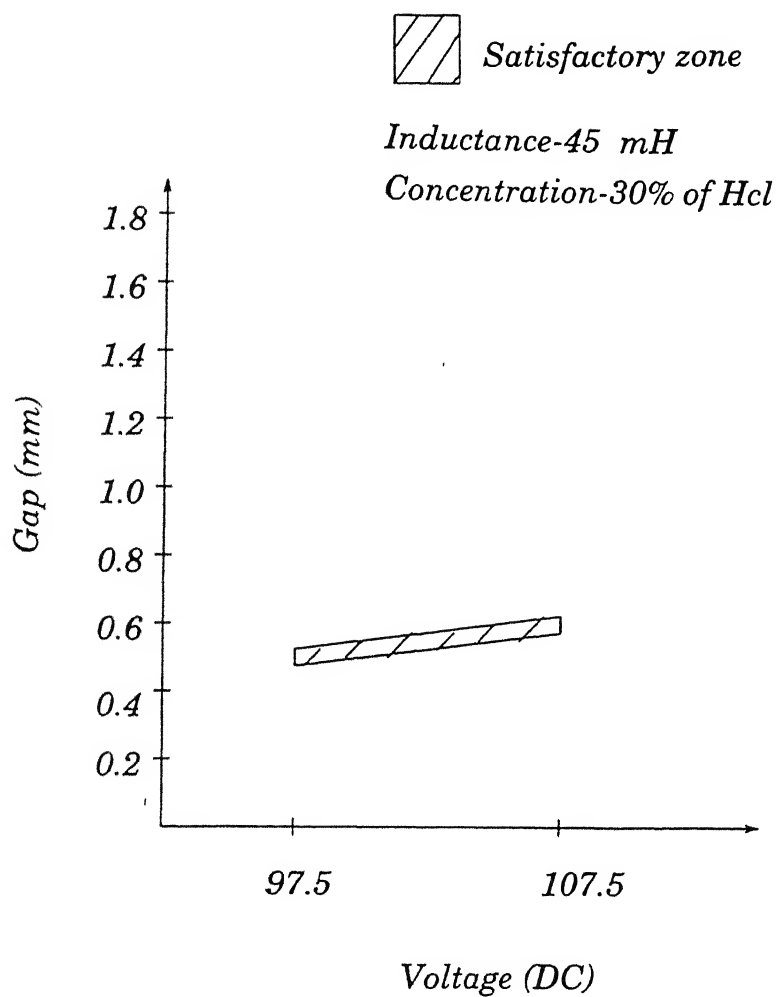


Figure 4.12: Relationship between voltage and concentration at 45mH and 30% concentration

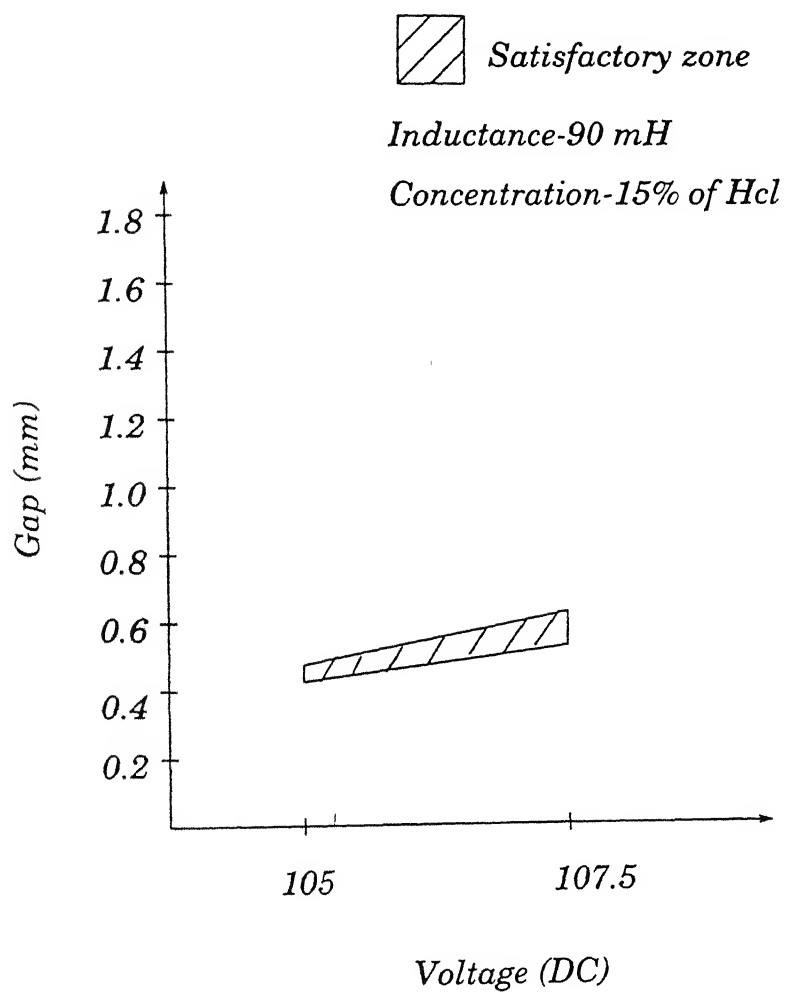


Figure 4 13: Relationship between voltage and concentration at 90mH and 15% concentration

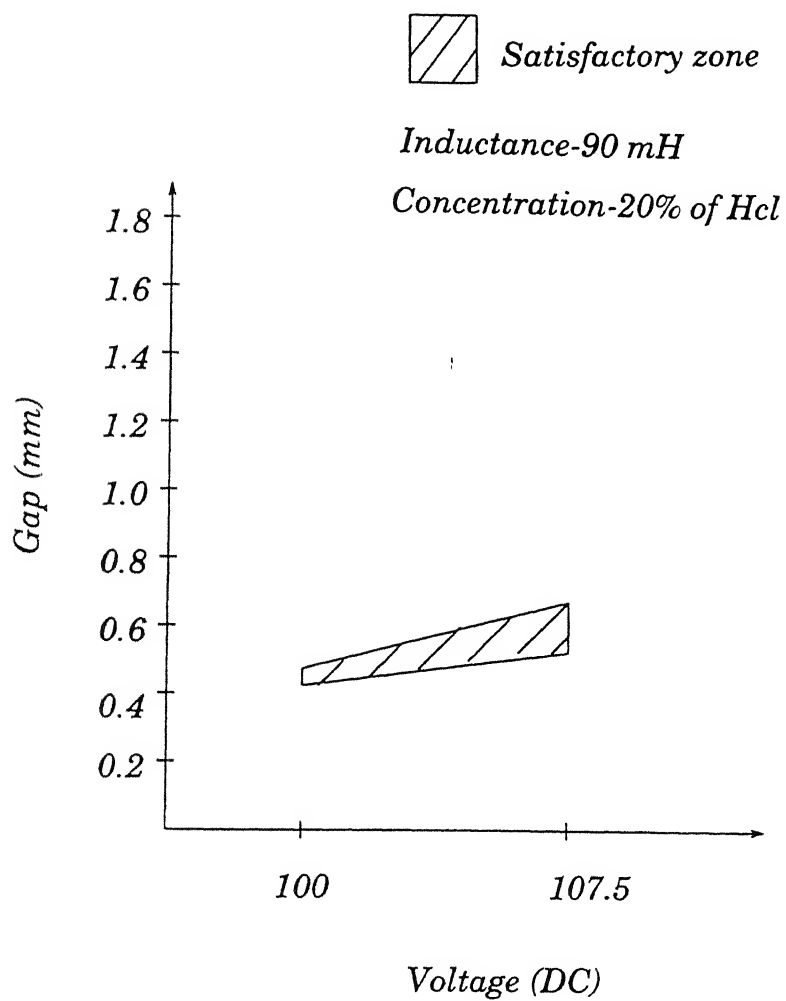


Figure 4.14: Relationship between voltage and concentration at 90mH and 20% concentration

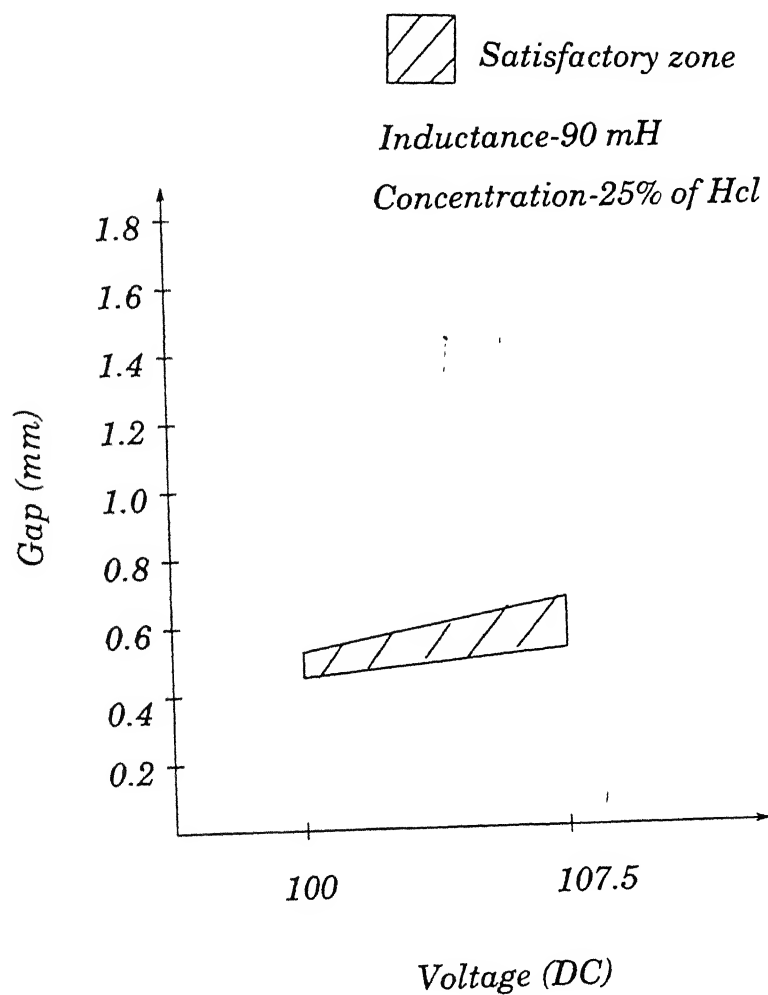


Figure 4.15: Relationship between voltage and concentration at 90mH and 25% concentration

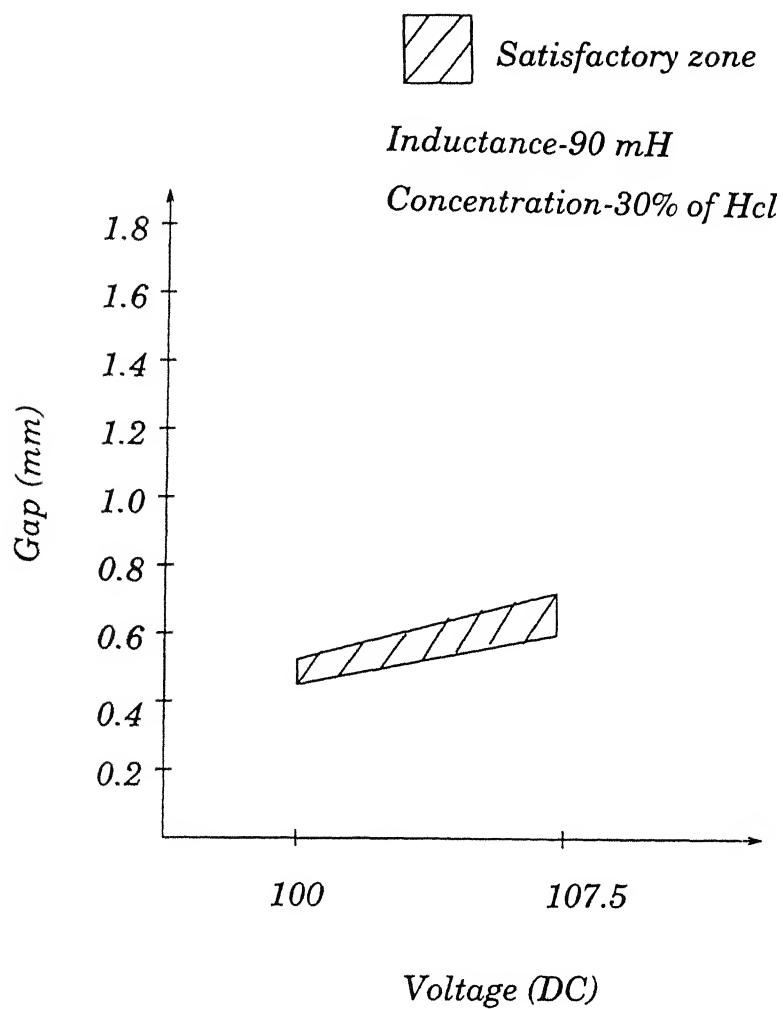


Figure 4.16: Relationship between voltage and concentration at 90mH and 30% concentration

4.2.3 Effect of concentration on strength

Figure 4.17 shows the effect of concentration on the strength for 30mH inductance. The general distribution for 30mH inductance is that the strength gradually increases, reaches a peak at about 25% concentration and then drops at 30% concentration. This drop suggests that there is an optimum concentration around 25% concentration in which there is a good balance between the intensity of spark produced and the energy dissipated as it travels from the cathode to the workpiece. Fig 4.18 shows the variation of strength with concentration for 45mH inductance. Here the distribution is such that the strength is constant between 20% and 25% concentration and suddenly increases at about 30% concentration. This sudden increase in strength can be attributed to the increase in the energy of the spark as the concentration increases. This increase in energy is greater than that in the previous case due to the extra inductance. Fig 4.19 shows the variation in the case of 90mH inductance. This is almost similar to that in the 90mH case. Here also there is little variation in the 20% to 25% range.

4.2.4 Effect of concentration on maximum strength

Out of the strength values obtained in the previous experiments, the maximum strength was taken and plotted against the concentration at various inductance values. This is shown in Fig 4.20 . It can be seen that as the concentration increases the inductance has a major role to play. As the concentration increases to a value above 25%, the maximum strength in the case of 90mH inductance is much greater than that of 45mH and 30mH. This is due to the increase in the intensity of the spark and relatively lower energy loss. In the medium concentration range of 20% to 25%, 30mH has a higher strength than 45mH and 90mH. In this range the lower intensity of the spark at 30mH is

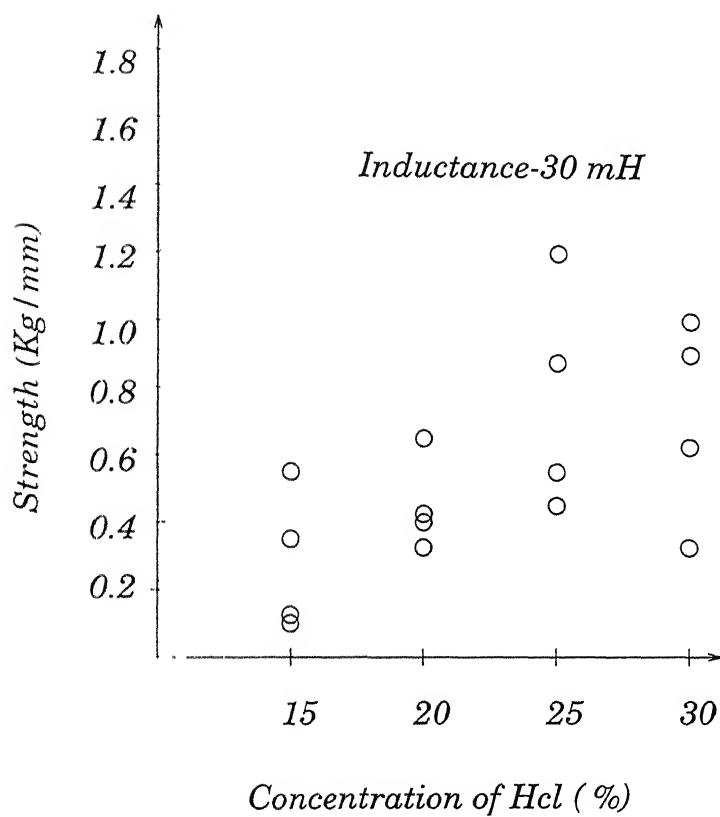


Figure 4.17: Figure showing relationship between strength and concentration at 30mH

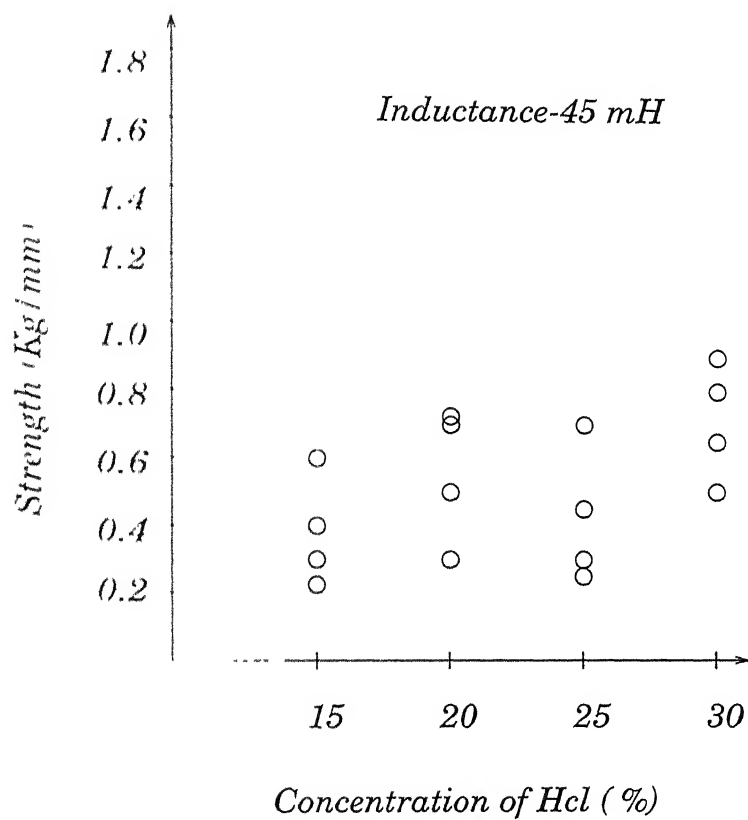


Figure 4.18: Figure showing relationship between strength and concentration at 45mH

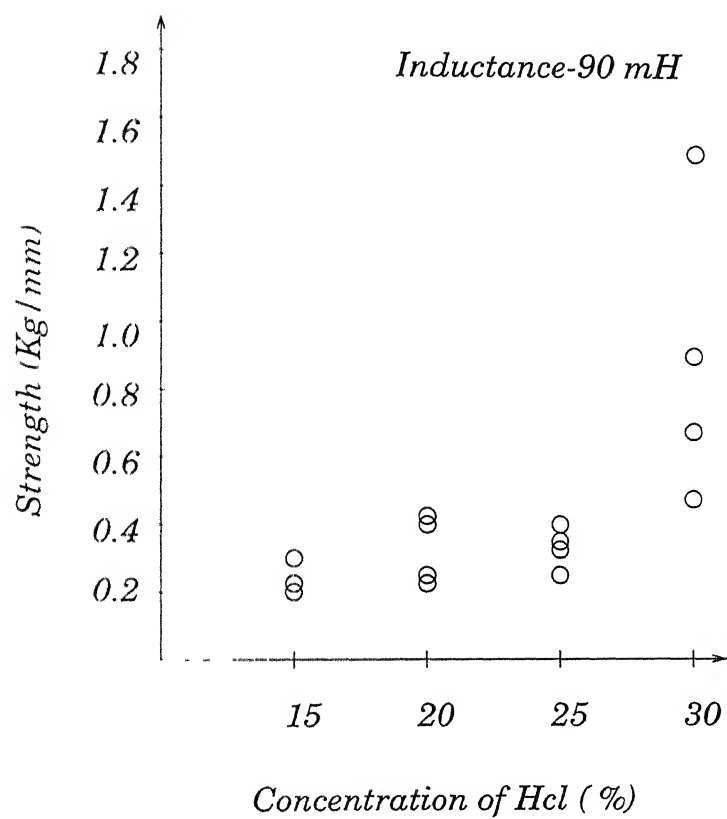


Figure 4.19: Figure showing relationship between strength and concentration at 90mH

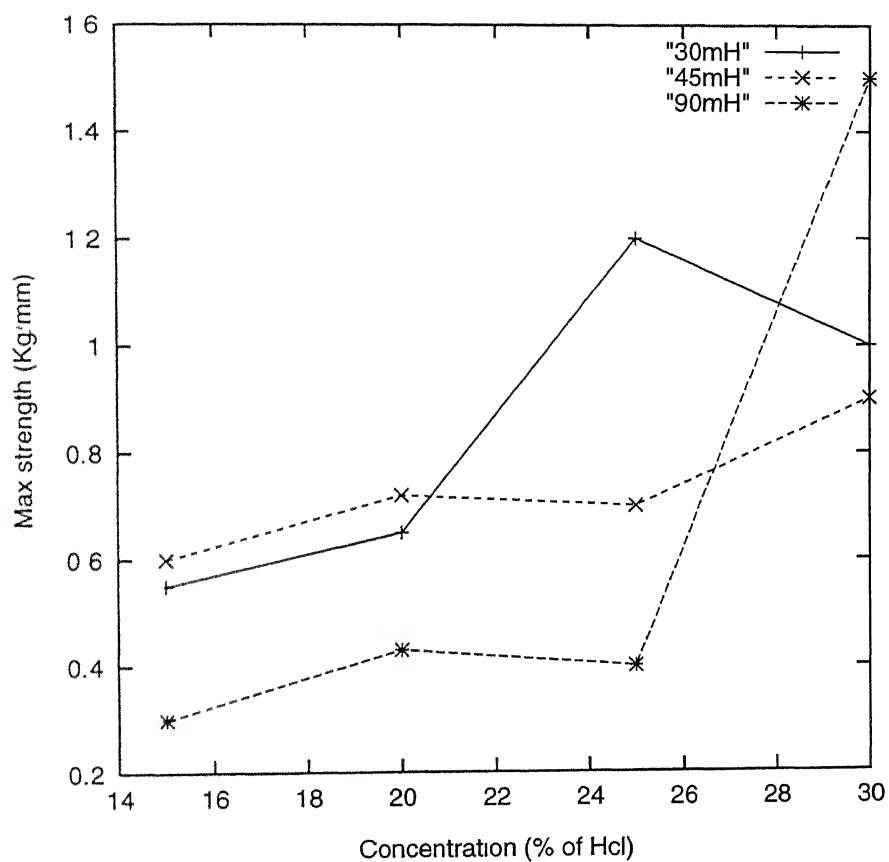
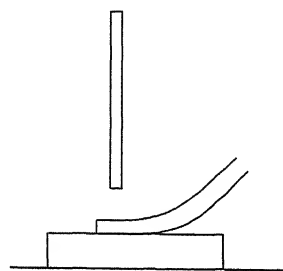


Figure 4.20: Variation of maximum strength with concentration

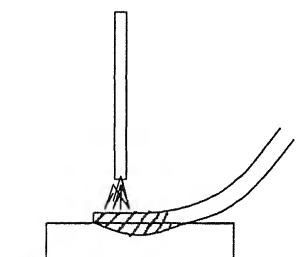
compensated by the correspondingly lower energy loss. In the 15% concentration range, the lower inductance produces better results than a high inductance values. These observations suggests that a low inductance value, preferably in the range of 30mH is the optimum for getting good microwelds.

4.3 Mechanism of ECD microwelding

From the study of ECD machining we find that material removal is by melting and/or vapourisation of the workpiece. In ECD microwelding, the sparks are directed at a point where both the wire and the plate are present. Due to the sparks, either melting and/or vapourising takes place. In the case of vapourisation, no welding takes place due to material removal of the sheet (machining) and wire breakage. In the case of melting, both the wire and the sheet metal fuse together forming a weld. It must be kept in mind that the sparks occur at the underside of the electrode and around the circumference. So the wire must be fed below the electrode. Feeding the wire from the side or through the electrode will not result in welding. This configuration is shown in the Fig 4.21 along with the mechanism of welding. One of the most important criteria for good welding to take place is that both the wire and the plate must be in constant touch with each other. This necessitates accurate feeding. This accuracy becomes even more critical when we consider the fact that the metal remains in the liquid state only for a short duration of time since it is submerged in the electrolyte.



Before welding



After welding

Figure 4 21: Mechanism of ECD microwelding

Chapter 5

CONCLUDING REMARKS

An experimental investigation of Electrochemical discharge microwelding was conducted in this thesis and the following conclusions can be drawn

- There exists a critical voltage below which there is no possibility of getting microwelds. This voltage is dependent upon concentration and inductance of the circuit
- The inductance is found to be the single most important factor affecting the performance of the process. It is also found that an inductance of 30 mH produces good microwelds. No welding takes place without inductance.
- The gap between the electrode and the plate also plays an important part in the process. It must be accurately maintained at a particular value throughout the process. This was found to be difficult to achieve in the present thesis because of lack of proper equipment. A servo controlled mechanism which monitors and controls the gap will be ideal.
- As was mentioned earlier, the wire must be fed in such a way that it must be in contact with the baseplate when the sparking occurs. Therefore

the feeding mechanism must be properly designed to achieve this with very thin wires.

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